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<b>(21) International Application Number:</b> PCT/US97/09531 <b>(22) International Filing Date:</b> 2 June 1997 (02.06.97)  <b>(30) Priority Data:</b> 60/018,747 31 May 1996 (31.05.96) US 08/866,544 30 May 1997 (30.05.97) US  <b>(71) Applicant:</b> BAYLOR COLLEGE OF MEDICINE [US/US]; One Baylor Plaza, Houston, TX 77030 (US).  <b>(72) Inventors:</b> CONNEELY, Orla, M.; 2601 South Braeswood #1307, Houston, TX 77025 (US). WARD, Pauline, P.; Baylor College of Medicine, Dept. of Cell Biology, One Baylor Plaza, Houston, TX 77030 (US).  <b>(74) Agents:</b> ABRAMS, Samuel, B. et al.; Pennie & Edmonds L.L.P., 1155 Avenue of the Americas, New York, NY 10036 (US).		<b>(81) Designated States:</b> AU, CA, CN, IL, JP, KR, MX, NO, NZ, PL, RU, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  <b>Published</b> <i>With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>
<b>(54) Title:</b> LACTOFERRIN VARIANTS AND USES THEREOF		
<b>(57) Abstract</b> <p>The present invention is directed to recombinant nucleic acids encoding lactoferrin variants and portions thereof, having modified iron-binding capacity, and to vectors comprising same recombinant nucleic acids. The present invention is further directed to methods of producing such vectors, and to transfected cells harboring the same. Methods for the production of lactoferrin variants and portions thereof, in various eukaryotic or prokaryotic cells are also provided. Finally, the invention is directed to lactoferrin variants and portions thereof encoded by the nucleic acids of the invention and produced by the processes of the invention. Thus, the invention provides an efficient and economical means for the production of recombinant lactoferrin variants and portions thereof.</p>		



## LACTOFERRIN VARIANTS AND USES THEREOF

### I. FIELD OF THE INVENTION

The present invention generally relates to lactoferrin related glycoproteins.

- 5 More specifically, the present invention relates to lactoferrin variants and portions thereof, their production and uses.

### II. BACKGROUND OF THE INVENTION

- Lactoferrin is a member of the transferrin family of non-heme iron binding glycoproteins (Aisen *et al.*, 1980, *Ann. Rev. Biochem.* 49:357-393), which includes  
10 transferrin, the major iron-transport protein in blood (MacGillivray *et al.*, 1983, *J. Biol. Chem.* 258:3543-3553), ovotransferrin, an avian egg white protein (Jeltsch *et al.*, 1982, *Eur. J. Biochem.* 122:291-295) and melanotransferrin, a membrane bound form of this family found in human melanocytes (Rose *et al.*, 1986, *Proc.*  
15 *Natl. Acad. Sci. USA* 83:1261-1265). Lactoferrin has a broad distribution, present in both external secretions that bathe the body surfaces (Masson *et al.*, 1971, *Comp. Biochem. Physiol.* 39:119-129; Hennart *et al.*, 1991, *Am. J. Clin. Nutr.* 53:32-39; Masson *et al.*, 1966, *Clin. Chim. Acta.* 14:735-739; Pentecost *et al.*, 1987, *J. Biol. Chem.* 262:10134-10139; Yu *et al.*, 1993, *Biochem. J.* 296:107-111)  
20 and in the secondary granules of polymorphonuclear neutrophils where it can be released into the bloodstream upon neutrophil activation (Masson *et al.*, 1969, *J. Exp. Med.* 130:643-658). The functions proposed for lactoferrin include iron binding and delivery to the small intestine (Fransson *et al.*, 1980, *J. Pediatrics* 96:380-384; Iyer *et al.*, 1993, *Eur. J. Clin. Nutr.* 47:232-241; Cox *et al.*, 1979, *Biochem. Biophys. Acta.* 558:129-141; Hu *et al.*, 1988, *Biochem. J.* 249:435-441;  
25 Gislason *et al.*, 1995, *J. Pediatr. Gastroent. Nutr.* 21:37-43; Mikogami *et al.*, 1994, *Am. J. Physiol.* 267:G1-G8; Ward *et al.*, 1995, *Biotechnology* 13:498-503), antimicrobial activity against a wide range of gram-negative and gram-positive bacteria (Oram *et al.*, 1968 *Biochem. Biophys. Acta.* 170:351-365; Arnold *et al.*,  
30 1977, *Science* 197:263-265; Ellison *et al.*, 1988, *Infect. Immun.* 56:2774-2781; Bellamy *et al.*, 1992, *Biochem. Biophys. Acta.* 1221:130-136; Yamauchi *et al.*, 1993, *Infect. Immun.* 61:719-728), cellular growth promotion (Hashizume *et al.*, 1983, *Infect. Immun.* 763:377-382; Nichols *et al.* 1987, *Pediatr. Res.* 21:563-567), regulation of myelopoiesis (Sawatzki *et al.*, 1989, *Blood Cells* 15:371-375;

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including, but not limited to, lactoferrin variants with higher affinity for iron for improved antimicrobial activities, lactoferrin variants with lower affinity for iron having improved iron releasing properties, or lactoferrin variants having modified pH dependent efficiencies for iron release.

5       The Applicants of the present invention have previously reported the high level production and characterization of recombinant human lactoferrin in the filamentous fungi, including *Aspergillus*. Ward *et al.*, 1995, *Biotechnology* 13:498-503; U.S. Patent Nos. 5,571,896, 5,571,619; and 5,571,697, incorporated by reference in their entirety. Nonwithstanding its distinct and unique  
10   carbohydrate composition, the recombinant protein was shown to be indistinguishable from human breast milk lactoferrin with respect to its physiological activities, including iron and receptor binding and antimicrobial activity. Hence, the availability of this expression system provides now the production of lactoferrin variants in sufficient quantities to address the  
15   structure/function role of this protein, in order to generate variants with improved properties.

### III. SUMMARY OF THE INVENTION

20       The present invention relates to nucleic acid sequences encoding lactoferrin variants or portions thereof, wherein the portion comprises a sequence corresponding to at least one iron binding site of lactoferrin. The lactoferrin variant or portion thereof is further defined by having a modified iron binding capacity when compared to *wild-type* lactoferrin.

25       Using site-directed mutagenesis, the present invention elucidates the contribution of the two-lobe structure to the unique iron binding properties of lactoferrin. Human lactoferrin cDNA was selectively mutated in the two tyrosine residues involved in iron binding in either or both halves of the protein. The resulting three iron binding defective variants were expressed in and purified from *Aspergillus awamori*. Iron binding analysis using  $^{59}\text{FeCl}_3$  confirmed that mutation  
30   of the two tyrosine residues involved in iron binding in either lobe, resulted in selective loss of iron binding to the mutated lobe. In addition, pH dependent iron-release studies demonstrated a differential iron binding stability of the two halves of lactoferrin, the amino-terminal lobe being much more acid-labile than the

Broxmeyer *et al.*, 1986, *Blood Cells* 13:31-48; Zucali *et al.*, 1979, *Blood* 54:951-954), and immunomodulatory properties (Machnicki *et al.*, 1993, *Int. J. Exp. Path.* 74:433-439; Crouch *et al.*, 1992, *Blood* 80:235-240; Zagulski *et al.*, 1989, *Br. J. Exp. Pathol.* 70:697-704).

5       Lactoferrin shares a high degree of structural homology with other members of the transferrin family. All of these proteins are monomeric glycoproteins with a molecular weight of ~ 80 kDa. Aisen *et al.*, 1980, *Ann. Rev. Biochem.* 49:357-393; Metz-Boutique *et al.*, 1984, *Eur. J. Biochem.* 145:659-676. The three dimensional structure of lactoferrin (Anderson *et al.*, 1989, *J. Mol. Biol.* 209:711-10   734) and transferrin (Lindley *et al.*, 1988, *Biochem.* 27:5804-5812) have been precisely defined by X-ray crystallographic analysis. The proteins are folded into two globular lobes corresponding to the amino- and carboxy-terminal halves of the protein. This bilobal structure, with ~ 40% conservation between the amino- and carboxy-terminal halves, is thought have evolved by intragenic duplication from a 15   common ancestral gene. Williams *et al.*, 1982, *Trends Biochem. Sci.* 7:394-397. Each of these lobes can reversibly bind iron with high affinity and with the concomitant binding of an anion, usually carbonate. Aisen *et al.*, 1980, *Ann. Rev. Biochem.* 49:357-393. The amino acids required for iron binding by lactoferrin are highly conserved between members of the transferrin family. Baker *et al.*, 20   1992, *J. Inorg. Biochem.* 47:147-160. In lactoferrin, an iron atom binds to Asp 396, Tyr 93, Tyr 193 and His 254 in the amino-terminal lobe, and the corresponding Asp 396, Tyr 436, Tyr 539 and His 598 in the carboxy-terminal lobe, respectively. Anderson *et al.*, 1989, *J. Mol. Biol.* 209:711-734.

Nonwithstanding their structural similarities, lactoferrin displays much more 25   avid iron binding properties than its serum counterpart, transferrin. In particular, the release of iron from lactoferrin displays greater pH stability than transferrin, the latter releasing iron in a pH range of about six (6) to about four (4) while the former releases iron a pH range of about four (4) to about two (2). Mazurier *et al.*, 1989, *Biochem. Biophys. Acta.* 629:399-408. It has been suggested that the unique 30   iron binding properties of lactoferrin contribute to some of the diverse functional activities proposed for this protein. Elucidation of the structural and functional features involved in the unique iron binding properties of lactoferrin will allow the modelling and generation of lactoferrin variants with improved properties,



#### IV. BRIEF DESCRIPTION OF THE DRAWINGS

FIGURES 1A and 1B depict a Western immunoblot and silver stain analysis of the purified iron binding defective lactoferrin variants.

FIGURE 1A depicts a Western immunoblot analysis of 200 ng samples of purified recombinant human lactoferrin (Rec hLF), amino-terminal (MN-2Y), carboxy-terminal (MC-2Y) and amino- and carboxy-terminal (MNC-4Y) iron binding defective variants of lactoferrin, respectively.

FIGURE 1B depicts a Silver-stained SDS-polyacrylamide gel analysis of purified Rec hLF, MN-2Y, MC-2Y and MNC-4Y (1  $\mu$ g each).

FIGURES 2A, 2B, 2C, and 2D depict competition of biotinylated recombinant lactoferrin binding to human enterocyte cells by the iron binding defective lactoferrin variants.

FIGURE 2A. Iron-saturated biotinylated recombinant human lactoferrin (0.4  $\mu$ M) was incubated with Caco-2 membranes (300 ng) in the presence or absence of increasing concentrations of unlabeled iron-saturated recombinant lactoferrin (Fe-RechLF) or apo-recombinant lactoferrin (Apo-RechLF). Inhibition of biotinylated lactoferrin binding to Caco-2 membranes was determined using a biotin/avidin microtiter assay (Ward *et al.*, 1995, *Biotechnology* 13:498-503).

FIGURES 2B, 2C, and 2D. Apobiotinylated recombinant human lactoferrin (0.4  $\mu$ M) was incubated with Caco-2 membranes (300 ng) in the presence or absence of increasing concentrations of unlabeled Apo-RechLF or MN-2Y (FIGURE 2B), MC-2Y (FIGURE 2C) or MNC-4Y (FIGURE 2D). Inhibition of biotinylated lactoferrin binding to Caco-2 membranes was determined using a biotin/avidin microtiter assay. The data are represented as means  $\pm$  S.E.M.

FIGURE 3 depicts iron-saturation analysis of the lactoferrin amino-terminal (MN-2Y), carboxy-terminal (MC-2Y) and amino- and carboxy-terminal (MNC-4Y) iron binding defective variants. Iron-free recombinant human lactoferrin (Rec hLF), MN-2Y, MC-2Y, and MNC-4Y were saturated with iron as described in the experimental procedures.  $^{59}\text{Fe}$  bound to the samples was quantified using liquid scintillation counting and the Fe/protein molar ratios were determined. The data are represented as means  $\pm$  S.E.M.

FIGURE 4 depicts pH-dependent release of  $^{59}\text{Fe}$  from the lactoferrin amino-terminal (MN-2Y) and carboxy-terminal (MC-2Y) iron binding defective variants.

carboxy-terminal lobe. More importantly, the present invention shows that a functional iron binding carboxy-terminal lobe is necessary for the pH stability of iron binding to the amino-terminal lobe which is characteristic of *wild-type* lactoferrin. These results support the conclusion that cooperative interactions  
5 between the two lobes of lactoferrin contribute to the unique iron binding properties of this protein.

Thus, the present invention provides guidance for the generation of lactoferrin variants having improved properties, such as modified iron binding characteristics, *e.g.*, increased or decreased affinity for iron, or modified pH or  
10 temperature requirements or ranges for iron binding. Furthermore, the present invention provides guidance for the modelling of lactoferrin variants having otherwise improved characteristics, *e.g.*, therapeutic tolerance, while retaining their iron binding activity.

In a second aspect, the present invention is further directed to vectors  
15 comprising nucleic acids encoding lactoferrin variants or portions thereof, suitable for expression of the lactoferrin variant or portion thereof in eukaryotic cells. Preferably, the plasmid are suitable for expression in fungal cells, including *Aspergillus oryzae*, *Aspergillus niger*, *Aspergillus nidulans* and *Aspergillus awamori*.

20 In a third aspect, the present invention is further directed to methods of producing such vectors, and to transfected cells harboring the same. Methods for the production of lactoferrin and variants thereof in various eukaryotic or prokaryotic cells are also provided. Finally, the invention is directed to lactoferrins and variants thereof produced by the processes of the invention. Thus,  
25 the invention provides an efficient and economical means for the production of recombinant lactoferrin protein and variants thereof, and lactoferrin related polypeptides.

increased or decreased iron binding capacity, or modified pH or temperature requirements or ranges for the binding of iron. Furthermore, the present invention provides guidance for the modelling of lactoferrin variants having otherwise improved characteristics, *e.g.*, therapeutic tolerance, stability against degradation,  
5 or immunoreactivity, while retaining their iron binding activity.

Accordingly, the present invention is directed to recombinant nucleic acids encoding lactoferrins variants and portions thereof, and to vectors comprising same recombinant nucleic acids. The present invention is further directed to methods of producing such vectors, and to transfected cells harboring the same. Methods for  
10 the production of lactoferrin variants and portions thereof in various eukaryotic or prokaryotic cells are also provided. Finally, the invention is directed to lactoferrins variants and portions thereof encoded by the nucleic acids of the invention and/or produced by the processes of the invention. Thus, the invention provides guidance for the design of lactoferrin variants or portions thereof having  
15 improved characteristics, and an efficient and economical means for the production of such lactoferrin variants and portions thereof.

#### **B. Contribution Of The Bilobal Structure Of Lactoferrin To Its Unique Iron Binding Properties**

20 In the present invention, a site-directed mutagenesis approach was used to investigate the contribution of the bilobal structure of lactoferrin to the unique iron binding properties of this protein.

More specifically, the two tyrosines involved in iron binding in either or both lobes of lactoferrin were mutated to corresponding alanine residues in order to  
25 produce three iron binding defective variants. These lactoferrin variants were expressed and purified from *A. awamori* as previously described for the *wild-type* protein. U.S. Patent No. 5,571,896; Ward *et al.*, 1995, *Biotechnology* 13:498-503. The size, immunoreactivity and functional activity of these lactoferrin variants as determined by silverstain, western immunoblotting and enteric receptor  
30 binding analysis were similar to *wild-type* recombinant human lactoferrin indicating that the amino-acid substitutions had no adverse effect on the protein. Iron-saturation analysis using  $^{59}\text{FeCl}_3$  showed that while the lactoferrin variant with an intact carboxy-terminal iron binding lobe saturate at the expected 1:1 ratio of iron

<sup>59</sup>Fe-saturated recombinant human lactoferrin (Rec hLF), MN-2Y and MC-2Y were dialyzed against buffers ranging in pH from 7-2. <sup>59</sup>Fe remaining bound to the lactoferrin samples after dialysis was quantified by liquid scintillation counting and the Fe/protein molar ratio was determined. The data are represented as means +/- S.E.M.

## V. DEFINITIONS

Terms used herein are in general as typically used in the art. The following terms are intended to have the following general meanings as they are used herein:

10 The term "*lactoferrin variant*" refers to a polypeptide generated by mutation of a naturally occurring lactoferrin in at least one amino acid position.

The term "*vector*" means plasmid, cosmid, phage, virus, retrovirus or other vehicle to allow insertion, propagation and/or expression of a nucleic acid encoding a lactoferrin variant or portion thereof.

15 The term "*host cell*" means any cell that will allow lactoferrin expression.

The term "*promotor*" means regulatory DNA sequences that controls transcription of the lactoferrin cDNA.

The term "*transformation*" means incorporation permitting expression of heterologous nucleic acid sequences by a cell.

20 The term "*iron binding capacity*" means ability to bind Fe. Fully functional human lactoferrin can bind two atoms of iron per molecule of lactoferrin.

The term "*biological activity/biological active*" means biological activity of lactoferrin as measured by its ability to bind iron, or kill microorganisms, or retard the growth of microorganisms, or to function as an iron transfer protein.

## VI. DETAILED DESCRIPTION OF THE INVENTION

### A. Overview

30 The present invention is based, in part, on the identification those domains, sequences, and structures in the lactoferrin polypeptide which contribute to the iron binding capacity/properties of the protein. As such, the present invention provides guidance for the generation of lactoferrin variants having improved characteristics, such as modified iron binding characteristics, *e.g.*,

The bias for selection of a bilobal structure in the evolution of the transferrin family is unknown. The instant disclosure provides a functional rationale for this selection in the case of lactoferrin. As such, the present invention shows that the evolution of a two lobe structure has endowed lactoferrin with

5 unique iron binding properties which are likely to impinge on the unique functional activity of this protein. Interestingly, transferrin differs from lactoferrin in that it has been shown that the pH dependent iron release properties of this protein and a proteolytically derived amino-terminal fragment are similar. Mazuier *et al.*, 1989, *Biochem. Biophys. Acta.* 629:399-408; Lineback-Zins *et al.*, 1980, *J. Biol. Chem.*

10 255:708-713. These findings may suggest that a lack of cooperativity between the two lobes of transferrin may be a critical factor accounting for the characteristically weaker iron binding stability of this protein. Taken together with the studies described herein, it is suggested that the different iron binding properties of lactoferrin and transferrin may be due, at least in part, to the evolution of a

15 carboxy terminal iron binding lobe of lactoferrin that has increased acid stability and functions cooperatively with the amino-terminal lobe to confer a pH stability to this lobe that is characteristic of the bilobal protein.

### C. Lactoferrin Variants

20 Based on its identification of those domains, sequences and structures in the lactoferrin polypeptide contributing to the iron binding properties of the protein, the present invention provides guidance for the design and generation of novel lactoferrin variants or portions thereof having a modified iron binding capacity. Typically, the lactoferrin variants of the invention have

25 improved properties, including, but not limited to, lactoferrin variants with higher affinity for iron for improved antimicrobial activities, lactoferrin variants with lower affinity for iron having improved iron-releasing properties, or lactoferrin variants having modified pH or temperature requirements or ranges for the binding and/or release of iron. In addition, the invention allows for the design of

30 lactoferrin variants having otherwise improved characteristics, *e.g.*, therapeutic tolerance, immunoreactivity, or biological half life, while retaining their iron binding capacity.

to protein, the variant with an intact amino-terminal iron binding function consistently saturated at less than 1:1 suggesting a reduced stability of iron binding of this lactoferrin variant at pH 7.0. In addition, iron binding studies demonstrated that mutation of the tyrosine residues in both lobes effectively disrupted the iron  
5 binding capacity of the complete protein. *See, Sections VII.A., VII.C., and VII.D.*

As disclosed herein, pH dependent iron-release studies from the non-mutated lobes showed that the stability of iron binding to the amino- and carboxy-terminal lobes of lactoferrin were dissimilar. The release of iron from the lactoferrin variant containing an intact carboxy-terminal iron binding function was  
10 similar to that observed for the native lactoferrin. In contrast, the lactoferrin variant with an intact amino-terminal iron binding site was much more acid-labile, releasing all of its bound iron between a pH of 7-5. Hence, despite the overall structural homology between these two lobes (40%), it is demonstrated that the amino- and carboxy-terminal lobes of lactoferrin differ in their pH stability of iron  
15 binding. Furthermore, it is demonstrated that a functional iron binding carboxy-terminal lobe is required to impart the iron binding stability to the amino-terminal lobe which is characteristic of the *wild-type* protein.

The non-equivalence of iron binding to the amino and carboxy terminal lobes of lactoferrin has been reported previously. Mazurier *et al.*, 1989, *Biochem.*  
20 *Biophys. Acta.* 629:399-408; Day *et al.*, 1992, *J. Biol. Chem.* 167:13857-13862; Shimazaki *et al.*, 1993, *J. Dairy Sci.* 76:946-955. Studies using a cloned amino-terminal fragment of human lactoferrin (Day *et al.*, 1992, *J. Biol. Chem.* 167:13857-13862) and a proteolytically derived carboxy-terminal fragment from bovine lactoferrin (Shimazaki *et al.*, 1993, *J. Dairy Sci.* 76:946-955) have shown a  
25 similar disparity in pH dependence of iron binding as reported in the present invention. However, while the previous reports did indicate that the carboxy-terminal lobe, or part thereof, was required to stabilize the amino-terminal lobe iron binding function, these studies were limited as it remained to be determined whether the structural presence of the carboxy-terminal lobe or a functional  
30 carboxy-terminal iron binding activity was required for stabilization of iron binding to the amino-terminal lobe. The present invention extends these studies and show that cooperative interactions, driven primarily by a functional carboxy-terminal lobe are necessary for iron binding stabilization.

adapted for this purpose, and typically drive expression of the desired gene from expression controls used naturally by the chosen host.

Because the lactoferrin variants of the invention typically, as natural occurring lactoferrin, requires post-translational modifications, such as glycosylation at several amino acid residues, many of the lactoferrins variants or portions thereof need to be produced in an eukaryotic host. In preferred embodiments, the lactoferrin product is produced by an *Aspergillus* expression system, as described in Ward *et al.*, 1992, *Gene* 122:219-223; and U.S. Patent Nos. 5,571,896 and 5,571,697, incorporated by reference in its entirety.

If unglycosylated forms of lactoferrin variants or portions thereof are produced, however, their production may conveniently be achieved in bacterial hosts such as *E. coli*. For such production, nucleic acid coding for the selected lactoferrin variant or portion thereof, may usefully be placed under an expression control, *e.g.*, of the lac, trp or PL genes of *E. coli*.

As an alternative to expression of nucleic acid coding for the lactoferrin variant or portion thereof *per se*, the host can be adapted to express the lactoferrin product as a fusion protein in which the lactoferrin product is linked releasably to a carrier protein that facilitates isolation and stability of the expression product.

In a further alternative, the lactoferrin variant or portion thereof may be generated by organic synthesis. In particular where production of a portion of a lactoferrin variant, *e.g.*, a peptide of about twenty (20) through about fifty (50) amino acids in length, is the objective preferably the well established techniques of automated peptide synthesis are employed, general descriptions of which appear, for example, in J.M. Stewart and J.D. Young, Solid Phase Peptide Synthesis, 2nd Edition, 1984, Pierce Chemical Company, Rockford, Illinois; and in M. Bodanszky and A. Bodanszky, The Practice of Peptide Synthesis, 1984, Springer-Verlag, New York; Applied Biosystems 430A Users Manual, 1987, ABI Inc., Foster City, California; and Solid Phase Peptide Synthesis - A Practical Approach, by: E. Atherton & R.C. Sheppard, IRL Press, Oxford (1989). In these techniques, the lactoferrin variant portion is grown from its C-terminal, resin-conjugated residue by the sequential addition of appropriately protected amino acids, using either the Fmoc or tBoc protocols.

The lactoferrin variants of the invention may be derived from *wild-type* lactoferrin of a variety of mammalian species, including, but not limited to, human, murine, rat, bovine, and porcine lactoferrin. The *wild-type* lactoferrin may be mutated by a variety of methods generally known in the art. See, among other places, Sambrook *et al.*, 1990, *Molecular Cloning: A Laboratory Manual*. Cold Spring Harbour Laboratory Press, New York; Kunkel *et al.*, 1987, *Meth. Enzymol.* 154:367-382; Kunkel, 1985, *Proc. Natl. Acad. Sci. USA* 82:488-492.

In a preferred embodiment, the lactoferrin variant comprises at least one mutation affecting at least one iron binding site. Such iron binding site may have modified iron binding characteristics when compared to *wild-type* lactoferrin. For example, affinity for iron may increased or decreased. In addition, affinity for iron may exhibit modified pH range characteristics. Alternatively, the iron binding site may be modified such that the lactoferrin variant or portion thereof does not bind iron at all.

In another embodiment, the lactoferrin variant does comprise at least one mutation effecting modification of the therapeutic tolerance, biological stability or immunotolerance of lactoferrin, while retaining its biological activity.

#### **D. Expression And Production Of Lactoferrin Variants**

The nucleic acid sequences of the invention encoding lactoferrin variants may be inserted in a vector suitable for its expression in a eukaryotic cell in such way that allows expression of the lactoferrin variant. Alternatively, nucleic acid sequences encoding portions of the lactoferrin variants of the invention may be inserted in vectors allowing their expression in eukaryotic cells. Preferably, the portion of the lactoferrin variant comprises at least one iron binding site, which may be modified.

In preferred embodiment, lactoferrin is produced in recombinant expression systems. See, among other places, Ward *et al.*, 1992, *Biotechnology* 10:784-789; Ward *et al.*, 1995, *Biotechnology* 13:498-503. For this purpose, nucleic acids coding for the desired form of lactoferrin (*see, e.g.*, U.S. Patent 5,571,691, incorporated by reference in its entity) is incorporated expressibly in a cellular host, which is then cultured under conditions appropriate for expression of that particular peptide or protein. A variety of gene expression systems have been



Treatment with the active ingredient may begin at any time after the indication to be treated, *e.g.*, infections, or skin disorders, *e.g.*, psoriasis, contact dermatitis, UV-induced inflammation, infant diaper rash, asthma, arthritis, and the like, is diagnosed. Preferably, treatment is commenced as a prophylactic or at  
5 early stages of the disease, in order to prevent massive infection or inflammation in the first place. Typically, treatment will continue until the disorder is cured. In cases of chronic diseases, such as psoriasis, asthma or arthritis, or in cases of continued exposure to an allergen, the treatment may have to be extended beyond the cure of the symptoms.

10 The dose administered will, of course, vary depending upon known factors, such as (1) the pharmacodynamic characteristics of the particular lactoferrin product and its mode and route of administration, (2) the age, health, height and weight of the recipient, (3) the nature and extent of the symptoms, (4) the kind of concurrent treatment(s), (5) the frequency of treatment(s), and (6) the effect  
15 desired. A daily dose of active ingredient can be determined by those skilled in the art depending on the above factors.

The active ingredient may be administered topically, as inhalant, or as injection, *e.g.*, in inflamed joints or cartilage. However, alternatively the lactoferrin variant may be administered orally in solid or semi-solid dosage forms,  
20 such as hard or soft-gelatin capsules, tablets, or powders, or in liquid dosage forms, such as elixirs, syrups, or suspensions. It can also be administered parenterally, in sterile liquid dosage forms. Other dosage forms are potentially possible such as patches or ointment or transdermal administration.

The lactoferrin variants of the invention may also be formulated as a slow  
25 release implantation device for extended and sustained administration of the lactoferrin product. Examples of such sustained release formulations include composites of biocompatible polymers, such as poly(lactic acid), poly(lactic-co-glycolic acid), methylcellulose, hyaluronic acid, collagen, and the like. The structure, selection and use of degradable polymers in drug delivery vehicles have  
30 been reviewed in several publications, including, A. Domb *et al.*, Polymers for Advanced Technologies 3:279-292 (1992). Additional guidance in selecting and using polymers in pharmaceutical formulations can be found in the text by M. Chasin and R. Langer (eds.), "Biodegradable Polymers as Drug Delivery Systems,

### **E. Applications**

The lactoferrin variants of the present invention may be used for a broad variety of applications.

For example, a lactoferrin variant or portion thereof having improved iron  
5 binding capacity may be used for antimicrobial applications, including the treatment of infections, as additive to human or animal foods, as additive for eyedrops, eardrops, contact lense and other eye care solutions, topical skin care products, mouthwashes, chewing gum and toothpaste.

Lactoferrin variants or portions thereof having modified pH or temperature  
10 requirements may also be useful for the above applications. They further may be used as therapeutic additives for enhanced or modified iron transport and delivery.

Other applications of lactoferrin variants and portions thereof include the treatment of inflammatory skin diseases, as described in the co-pending provisional application, identified as Attorney Docket Number 8206-041-888, filed April 10,  
15 1997, hereby incorporated by reference in its entirety.

For many of the above identified applications, which are only to be understood as examples, lactoferrin variants and portions thereof having improved therapeutic tolerance, modified biological stability, or immunotolerance, may be particularly preferred.

20

### **F. Pharmaceutical Formulation And Routes Of Administration**

For therapeutic use, the lactoferrin variants or portions thereof chosen can be administered by any conventional means available for use in conjunction with pharmaceuticals, either as individual therapeutic agents or in a  
25 combination of therapeutic agents. Each can be administered alone but is generally administered with a pharmaceutical carrier selected on the basis of the chosen route of administration and standard pharmaceutical practice. The pharmaceutical compositions of the invention may be adapted for oral, parenteral, topical or rectal administration, or as inhalant, and may be in unit dosage form, in a manner well  
30 known to those skilled in the pharmaceutical art. Parenteral administration includes but is not limited to, injection subcutaneously, intravenously, intraperitoneally or intramuscularly.

apparent to those skilled in the art from the foregoing description and accompanying drawings. Such modifications are intended to fall within the scope of the appended claims.

## 5 VII. EXAMPLES

### A. Materials And Methods

**Construction Of pPLF-26, A Universal *Aspergillus Awamori* Expression Vector.** The construction of an expression vector, pPLF-19, for production of lactoferrin in *A. awamori* has previously been described. Ward *et al.*, 1995, *Biotechnology* 13:498-503; U.S. Patent No. 5,571,896. In order to construct an expression vector containing unique sites for cloning cDNAs encoding lactoferrin variants, pPLF-26 was generated. Briefly, pPLF-18 (Ward *et al.*, 1995, *Biotechnology* 13:498-503) was digested with SphI generating two fragments of 3.3 kb and 4.4 kb. The 3.3 kb SphI fragment containing the lactoferrin cDNA was subcloned into SphI digested pALTER (Promega, Madison, WI) generating pLF18sp.Alt. The 4.4 kb SphI fragment was relegated generating PR18.2. *In vitro* mutagenesis using the commercially available pALTER kit (Promega, Madison, WI) was used to introduce a NotI restriction enzyme site at the start of mature lactoferrin cDNA in pLF18Sp.Alt generating pNot.9. The 5' phosphorylated oligonucleotide used for the mutagenesis was as follows: 5' AGCGCGGCCGCAGGAGAAGGA 3' [SEQ ID NO:1]. PR18.2 was digested with EcoRI and the resulting two fragments were repaired using the Klenow fragment of DNA polymerase I and religated in the correct orientation. The resulting plasmid, p $\Delta$ E12, was digested with SphI and ligated with a 3.3 kb SphI fragment from pNot.9 generating pPLF-25. PLO3, encoding the phleomycin resistance gene under the control of the  $\beta$ -tubulin promoter (Gatignol *et al.*, 1987, *Mol. Gen. Genet.* 207:342-348) was digested with EcoRI and the resulting fragments were repaired using the Klenow fragment of DNA polymerase I and religated in the correct orientation. The resulting vector, PLO3 $\Delta$ R1, was digested with *Hind*III and the resulting 2.3 kb fragment was subcloned into *Hind*III digested pPLF-25 in the same orientation as the lactoferrin cDNA generating pPLF-26.

**Constructing Of Iron Binding Defective Variants Of Lactoferrin, MN-2Y, MC-2Y And MNC-4Y.** Synthetic 5' phosphorylated oligonucleotides with

" Vol. 45 of "Drugs and the Pharmaceutical Sciences," M. Dekker, New York, 1990. Liposomes may also be used to provide for the sustained release of a lactoferrin variant or portion thereof. Details concerning how to use and make liposomal formulations of drugs of interest can be found in, among other places, 5 U.S. Pat. No 4,944,948; U.S. Pat. No. 5,008,050; U.S. Pat. No. 4,921,706; U.S. Pat. No. 4,927,637; U.S. Pat. No. 4,452,747; U.S. Pat. No. 4,016,100; U.S. Pat. No. 4,311,712; U.S. Pat. No. 4,370,349; U.S. Pat. No. 4,372,949; U.S. Pat. No. 4,529,561; U.S. Pat. No. 5,009,956; U.S. Pat. No. 4,725,442; U.S. Pat. No. 4,737,323; U.S. Pat. No. 4,920,016. Sustained release formulations are of 10 particular interest when it is desirable to provide a high local concentration of a lactoferrin variant, *e.g.*, in arthritic joints, or at local skin inflammations, etc.

Gelatin capsules or liquid-filled soft gelatin capsules may contain the active ingredient and powdered or liquid carriers, such as lactose, lecithin starch, cellulose derivatives, magnesium stearate, stearic acid, and the like. Similar 15 diluents can be used to make compressed tablets. Both tablets and capsules can be manufactured as sustained release products to provide for continuous release of medication over a period of hours. Compressed tablets can be sugar-coated or film-coated to mask any unpleasant taste and to protect the tablet from the atmosphere, or enteric-coated for selective disintegration in the gastrointestinal tract. Liquid dosage forms for oral administration can contain coloring and/or 20 flavoring to increase patient acceptance.

Suitable pharmaceutical carriers are further described in Remington's Pharmaceutical Sciences, 17th ed., Mack Publishing Company, Easton, PA (1990) a standard reference text in this field, which is incorporated herein by reference in 25 its entirety.

The below examples explain the invention in more detail. The following preparations and examples are given to enable those skilled in the art to more clearly understand and to practice the present invention. The present invention, 30 however, is not limited in scope by the exemplified embodiments, which are intended as illustrations of single aspects of the invention only, and methods which are functionally equivalent are within the scope of the invention. Indeed, various modifications of the invention in addition to those described herein will become

transformed into *A. awamori* and transformants obtained were cultured for 7 days as previously described. Ward *et al.*, 1995, *Biotechnology* 13:498-503. The culture medium was screened for the iron binding variants using an ELISA assay. Vilja *et al.*, 1985, *J. Immunol. Meth.* 76:73-83. Positive cultures (> 50 mg/l) were  
5 cultured in 2 liter flasks for 7 days and the lactoferrin variant was purified using ion-exchange chromatography using CM-sephadex. Ward *et al.*, 1995, *Biotechnology* 13:498-503. The proteins were dialyzed against 0.1 M citric acid followed by extensive dialysis against H<sub>2</sub>O and 5 mM sodium phosphate, pH 7.5 (3 g).

10 **Receptor Binding Assays.** Receptor binding assays were performed using a biotin/avidin microliter plate assay (Rejman *et al.*, 1994, *Int. J. Biochem.* 26:201-206) using 8 day old Caco-2 solubilized membranes (300 ng) essentially as described. Ward *et al.*, 1995, *Biotechnology* 13:498-503.

***Iron-Saturation And PH Stability Of Iron Binding To The Lactoferrin***

15 **Variants.** MN-2Y, MC-2Y and MNC-4Y (5 mg) were incubated with a four-fold excess of FeCl<sub>3</sub>:<sup>59</sup>FeCl<sub>3</sub>:NTA (400:1:8). Ward *et al.*, 1995, *Biotechnology* 13:498-503. The samples were incubated at room temperature for 30 minutes. The samples were purified through NAP-10 column (Pharmacia, Piscataway, NJ) followed by dialysis against 0.05 M Tris/HCl, 0.2 M NaCl, pH 7.0 for 12 hours to  
20 remove any non-specific iron bound to the lactoferrin variants. Iron bound to the lactoferrin variants after dialysis was quantified by liquid scintillation counting. The pH stability of iron binding for each of the lactoferrin variants was carried out as described previously. Ward *et al.*, 1995, *Biotechnology* 13:498-503.

25 **B. Example 1: Expression And Purification Of Iron Binding Defective Variants In The Amino And Carboxy-Terminal Domains Of Lactoferrin**

In order to examine the contribution of the two-domain structure to the unique iron binding properties of lactoferrin, a site-directed mutagenesis  
30 approach was used to generate mutations in the human lactoferrin cDNA which encoded proteins which were defective in iron binding in either or both lobes of the protein.

EcoRI/BamHI ends, were generated in order to introduce a NotI site into pALTER. The sequence of the oligonucleotides were as follows. Top strand 5'GATCCATGCGGCCGCATG 3' [SEQ ID NO:2]. Bottom strand: 5'AATTCATGCGGCCGCATG 3' [SEQ ID NO:3]. The oligonucleotides were  
5 annealed and ligated into EcoRI/BamHI digested pALTER generating pALTLink. pPLF-26 was digested with NotI/EcoRI and the resulting 2.1 kb fragment containing the human lactoferrin cDNA was subcloned into NotI/EcoRI digested pALTLink. The resulting plasmid, pALThLF was used for subsequent  
10 mutagenesis experiments. The tyrosine residues involved in iron binding by lactoferrin in the amino-terminal lobe (Tyr 93, Tyr 193), carboxy-terminal lobe (Tyr 436, Tyr 529 and amino- and carboxy-terminal lobes (Tyr 93, Tyr 193, Tyr 436 and Tyr 529) were converted to corresponding alanine residues using *in vitro* mutagenesis using the pALTER kit. The 5' phosphorylated oligonucleotides used for the mutagenesis were as follows.

15

Tyr 93 → Ala 93: 5' CACAGCCACGGCATAAGCGTGAGTTCGTGGCTG 3' [SEQ ID NO:4];

TYR 193 → Ala 193: 5' CTTGAAGGCACCAGAGGCGCTGAAGTACGGTTC 3' [SEQ ID NO:5];

20 Tyr 436 → Ala 436: 5' CACCGCCACAGCAAGGGCTCCTTCCACAGGTCT 3' [SEQ ID NO:6];

Tyr 529 → Ala 529: 5' CCGGAAAGCCCCAGTGGCGCCGTAGTATCTCTC 3' [SEQ ID NO:7].

25 The resulting plasmids, pALTMN-2Y, pALTMC-2Y, and pALTMNC-4Y, were digested with NotI/EcoRI and subcloned into NotI/EcoRI digested pPLF-26 generating expression plasmids suitable for expression of lactoferrin in *Aspergillus* fungal cells, *i.e.*, p26MN-2Y, p26MC-2Y and p26MNC-4Y, respectively. All oligonucleotides sequences and construction junction were sequenced using the  
30 commercially available Sequenase Version 2.0 kit (United States Biochemical Corporation, Cleveland OH).

**Expression And Purification Of MN-2Y, MC-2Y And MNC-4Y.** The *A. awamori* expression vectors, p26MN-2Y, p26MC-2Y and p26MNC-4Y were

*Biochem. Biophys. Acta.* 558:129-141; Hu *et al.*, 1988, *Biochem. J.* 249:435-441; Gislason *et al.*, 1995, *J. Pediatr. Gastroent. Nutr.* 21:37-43; Mikogami *et al.*, 1994, *Am. J. Physiol.* 267:G1-G8; Ward *et al.*, 1995, *Biotechnology* 13:498-503.

Hence, as a prerequisite to using competitive receptor binding assay for the iron binding lactoferrin variants, the relative receptor binding kinetics of iron-free  
5 versus iron-saturated recombinant lactoferrin needed to be established.

Competitive receptor binding assays were performed as described previously. Ward *et al.*, 1995, *Biotechnology* 13:498-503. Biotinylated iron-saturated recombinant human lactoferrin (0.4  $\mu$ M) was incubated with human  
10 enteric Caco-2 cell membranes in the presence of O-20 fold molar excess of unlabelled apo- or iron-saturated recombinant human lactoferrin and a biotin/avidin microtiter assay was performed. Ward *et al.*, 1995, *Biotechnology* 13:498-503. The results of this analysis are shown in FIGURE 2A. Surprisingly, both apo- and iron-saturated lactoferrin showed comparable capacity to displace binding of iron-  
15 saturated biotinylated lactoferrin to the human enteric Caco-2 cell membranes indicating that both forms of lactoferrin have similar affinity for the lactoferrin enterocyte receptor. While lactoferrin has been proposed to deliver iron to enterocyte cells through these receptors, the similar relative receptor binding affinities of iron-free and iron-saturated lactoferrin suggest that the ability of  
20 lactoferrin to deliver iron via these receptors depends primarily on the relative amounts of iron-saturated versus iron-free lactoferrin present in the intestinal lumen.

Having established the affinity of apo-lactoferrin for its enteric receptor, competitive receptor binding assays with the lactoferrin variants were performed as  
25 described above to compare their functional activity with that of the *wild-type* protein. The results of this analysis are shown in FIGURES 2B, 2C, and 2D. All three iron binding defective variants showed no significant differences (< 2-fold variation) in their capacity to specifically inhibit the binding of iron-free biotinylated lactoferrin to Caco-2 membranes as compared to *wild-type* protein.  
30 These results indicate that mutation of the tyrosine residues did not disturb the iron-independent receptor binding functional activity of the protein.

Specifically, Tyr 93, Tyr 193 were mutated to Ala 93, Ala 193 generating a variant unable to bind iron in the amino-terminal half of lactoferrin (MN-2Y). The corresponding tyrosine residues in the carboxy-terminal half of lactoferrin Tyr 436, Tyr 529 were converted to alanine residues resulting in inactivation of the iron binding function of the carboxy-terminal domain (MC-2Y). All four tyrosine residues involved in iron binding by lactoferrin, *i.e.*, Tyr 93, Tyr 193, Tyr 436 and Tyr 529, were also mutated to corresponding alanine residues generating a variant which was unable to bind iron in both lobes of lactoferrin (MNC-4Y).

The lactoferrin variants were expressed and purified from *A. awamori* as previously described for recombinant human lactoferrin. Ward *et al.*, 1995, *Biotechnology* 13:498-503, U.S. Patent No. 5,571,896. The purified proteins were subjected to polyacrylamide gel electrophoresis followed by either western immunoblot analysis or silver stain analysis. *See*, FIGURE 1. Western immunoblot analysis using a specific polyclonal IgG directed against human lactoferrin detected an immunoreactive band corresponding to the size of *wild-type* recombinant lactoferrin for each of the three lactoferrin variants, as depicted in FIGURE 1A, lane 1-4. Analysis of a duplicate gel by silver stain analysis showed that the lactoferrin variants were >95% pure and a single band at the expected molecular weight of ~80 kDa was observed for each of the proteins. *See*, FIGURE 1B, lane 1-4. Hence, the size and immunoreactivity of the lactoferrin variants were indistinguishable from *wild-type* recombinant lactoferrin.

**C. Example 2: The Iron Binding Defective Variants Of Lactoferrin Have Similar Enteric Receptor Binding Properties To *Wild-Type* Recombinant Human Lactoferrin**

Based on the similarity of the amino acids alanine and tyrosine, it could be assumed that single amino-acid substitutions of tyrosine to alanine residues in the iron binding lactoferrin variant would result in minimal structural to the protein. Thus, the activity of the iron binding defective variants which are independent of iron binding, should be similar to that of *wild-type* recombinant human lactoferrin. Applicants and others have previously shown the presence of specific and saturable receptors for iron-saturated lactoferrin on human enterocyte cells. Iyer *et al.*, 1993, *Eur. J. Clin. Nutr.* 47:232-241; Cox *et al.*, 1979,



containing an intact amino-terminal iron binding lobe, was markedly different. Release of iron from this variant began at a pH of 7.0, which is consistent with the lower than 1:1 iron saturation of MC-2Y (FIGURE 4). In addition, iron release from MC-2Y was completed at a pH of 5.0. These results indicate that the amino-  
5 and carboxy-terminal lobes of lactoferrin differ in their pH stability of iron binding and a functional iron binding carboxy-terminal lobe is required to confer an increased pH stability to the amino-terminal domain that is characteristic of the *wild-type* protein. Based on these observations, it can be concluded that cooperative interactions between the two halves of lactoferrin, driven primarily by  
10 the carboxy-terminal lobe, contribute to the pH stability of iron binding that is unique to this protein.

All references cited within the body of the instant specification are hereby incorporated by reference in their entirety.

**D. Example 3: Mutation Of The Tyrosine Residues Involved In Iron Binding In The Amino- And Carboxy-Terminal Lobes Of Lactoferrin Selectively Disrupts The Iron Binding Capacity Of The Mutated Lobes Of The Protein**

5 To confirm that mutation of the two tyrosine residues in either or both lobes of lactoferrin was sufficient to disrupt the iron binding ability of the mutated lobe, iron-saturation analysis using  $^{59}\text{FeCl}_3$  was performed.

The results of this analysis are shown in FIGURE 3. In the presence of a 4-fold excess of iron, the *wild-type* recombinant lactoferrin saturated at a 2:0 molar ratio of iron/protein as expected. While MN-2Y having an intact carboxy-terminal iron binding function was saturated at a 1:1 molar ratio, MC-2Y having an intact amino-terminus was saturated at less than 1:1 ratio indicating some possible iron loss from this lactoferrin variant at pH 7.0. Hence disruption of the tyrosine residues involved in iron binding in either the amino or carboxy terminal half o  
10 lactoferrin selectively abolished the iron binding ability of only the mutated lobe. In addition, the results from this analysis demonstrated that mutation of all four tyrosine residues involved in iron binding by lactoferrin effectively ablated the iron binding ability of this protein.

20 **E. Example 4: Cooperativity Between The Amino- And Carboxy-Terminal Lobes Of Lactoferrin Contribute To The Unique Iron Binding Stability Of This Protein**

Having established that the iron binding defective lactoferrin variants were similar to *wild-type* recombinant lactoferrin, as determined by size, immunoreactivity and receptor-binding analysis, the pH-dependent iron release  
25 from these lactoferrin variants was analyzed to determine the contribution of the two-lobe structure to the iron binding stability of lactoferrin.

The lactoferrin variants were saturated with  $^{59}\text{FeCl}_3$  and dialyzed against buffers ranging in pH from 7-2 for 48 hours at 4°C. The amount of iron  
30 remaining bound to the lactoferrin variants was quantified by liquid scintillation counting. The results of this analysis are shown in FIGURE 4. The iron release profile from MN-2Y, containing an intact carboxy-terminal iron binding lobe, was similar to that of recombinant lactoferrin, iron release beginning at a pH of 5.0 and completed at pH 2.0. In contrast, the pH dependent release of iron from MC-2Y,

9. The eukaryotic cell of Claim 8, wherein said eukaryotic cell is a fungal cell selected from the group consisting of *Aspergillus oryzae*, *Aspergillus niger*, *Aspergillus nidulans* and *Aspergillus awamori*.
10. A transformed eukaryotic cell comprising a vector of Claim 6.
11. The eukaryotic cell of Claim 10, wherein said cell is selected from the group consisting of fungal, mammalian and insect cells.
12. The eukaryotic cell of Claim 11, wherein said eukaryotic cell is a fungal cell selected from the group consisting of *Aspergillus oryzae*, *Aspergillus niger*, *Aspergillus nidulans* and *Aspergillus awamori*.
13. A method for producing the lactoferrin variant or portion thereof of Claim 1 which comprises the following steps:
  - (a) transforming a eukaryotic cell with a vector containing:
    - i) the nucleic acid of Claim 1; and
    - ii) a promoter, and transcription and translation initiation and termination sequences;wherein said vector is adapted for the expression of the lactoferrin variant or portion thereof in a eukaryotic cell; and
  - (b) culturing said transformed eukaryotic cell in a suitable nutrient medium until lactoferrin variant protein is formed, secreted into the nutrient medium, and isolated therefrom.
14. A lactoferrin variant or portion thereof encoded by the nucleic acid of Claim 1.
15. A lactoferrin variant selected from the group consisting of MN-2Y, MC-2Y and MNC-4Y.

## CLAIMS

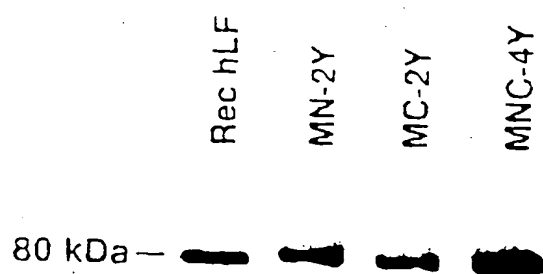
## WHAT IS CLAIMED:

1. A nucleic acid sequence encoding a lactoferrin variant or portion thereof, wherein said portion is further defined to comprise a sequence corresponding to at least one iron binding site of lactoferrin, and wherein the lactoferrin variant or portion thereof has a modified iron binding capacity.
2. A nucleic acid sequence encoding a lactoferrin variant selected from the group consisting of MN-2Y, MC-2Y and MNC-4Y.
3. A recombinant vector comprising:
  - (a) a promoter;
  - (b) DNA encoding for the lactoferrin variant or portion thereof of Claim 1; and
  - (c) transcription and translation initiation and termination sequences;wherein said vector is capable of producing the lactoferrin variant and expressing same as a processed protein.
4. A vector adapted for the expression of a lactoferrin variant or portion thereof in a eukaryotic cell, wherein said vector comprises DNA encoding a lactoferrin variant protein or portion thereof of Claim 1 and regulatory elements necessary for the expression of said DNA in said cell.
5. A vector comprising:
  - (a) a nucleic acid encoding the lactoferrin variant or portion thereof of Claim 1; and
  - (b) a promoter, and transcription and translation initiation and termination sequences;wherein said vector is used for the expression of human lactoferrin in a eukaryotic cell.
6. A vector selected from the group consisting of p26MN-2Y, p26MC-2Y and p26MNC-4Y.
7. A transformed eukaryotic cell comprising the vector of Claim 5.
8. The eukaryotic cell of Claim 7, wherein said cell is selected from the group consisting of fungal, mammalian and insect cells.



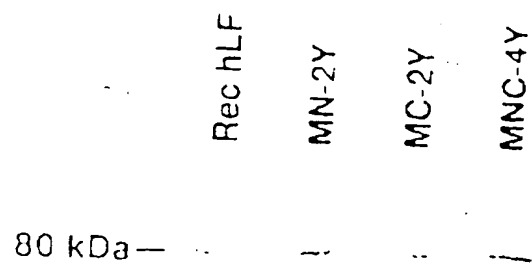
1/8

FIGURE 1A



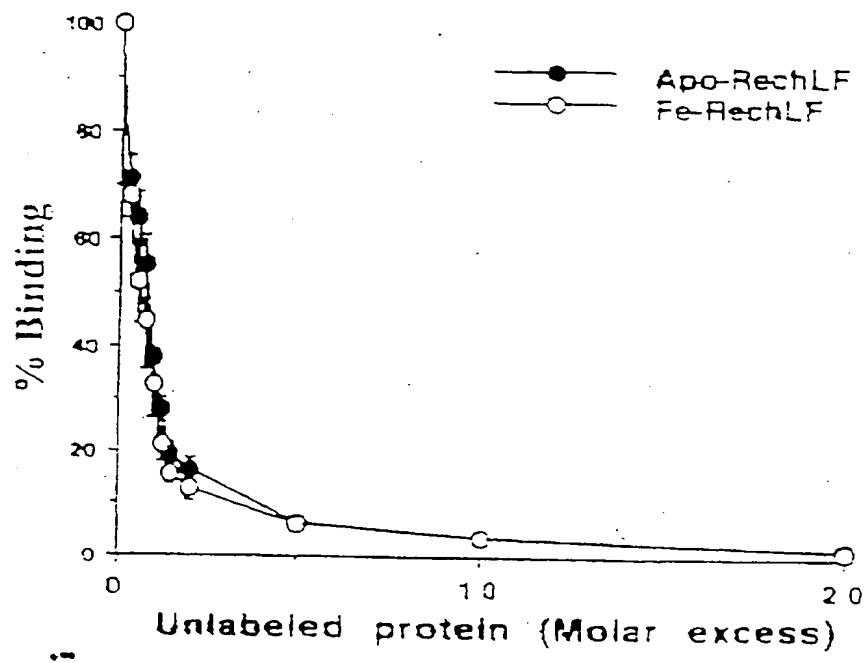
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## FIGURE 1B



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FIGURE 2A





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FIGURE 2B

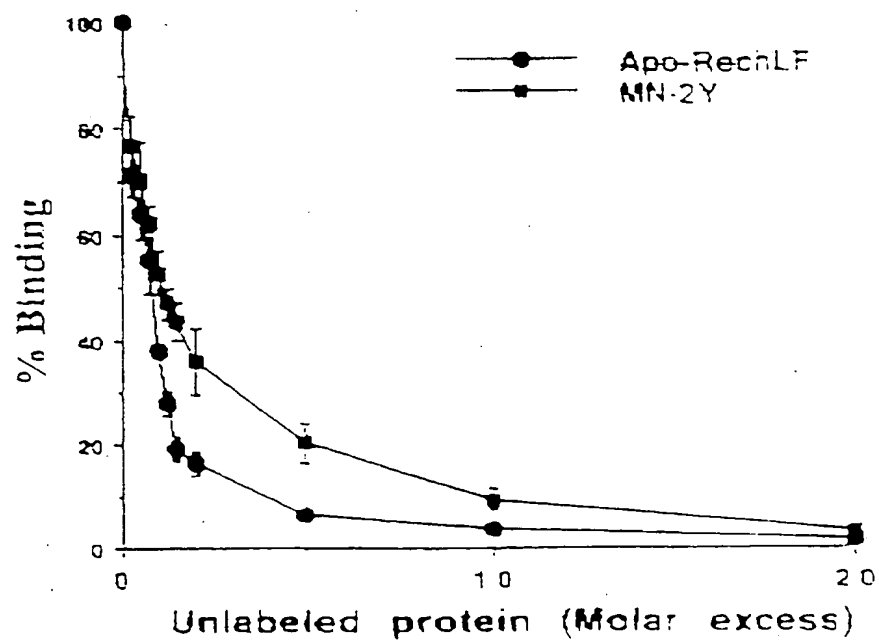
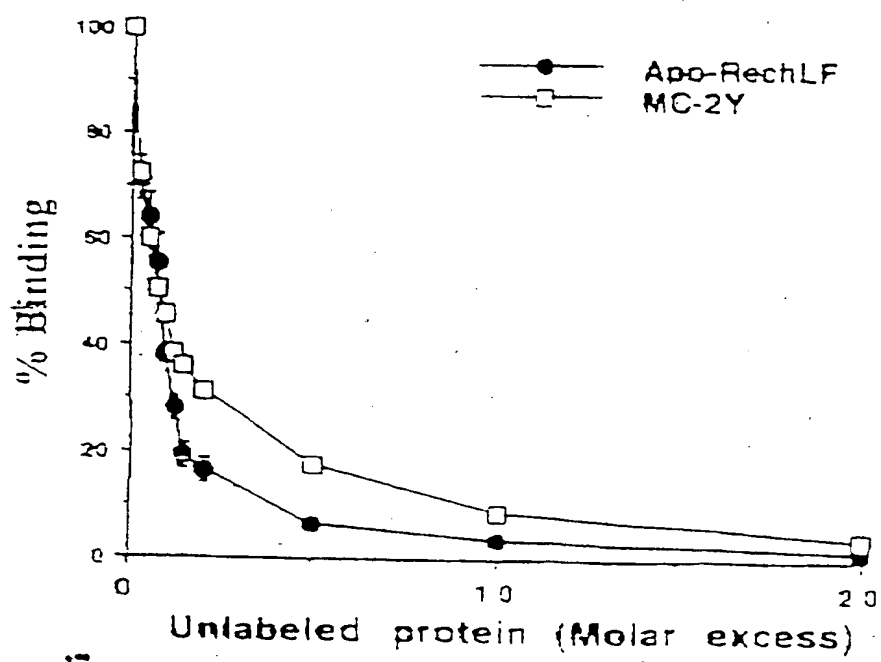
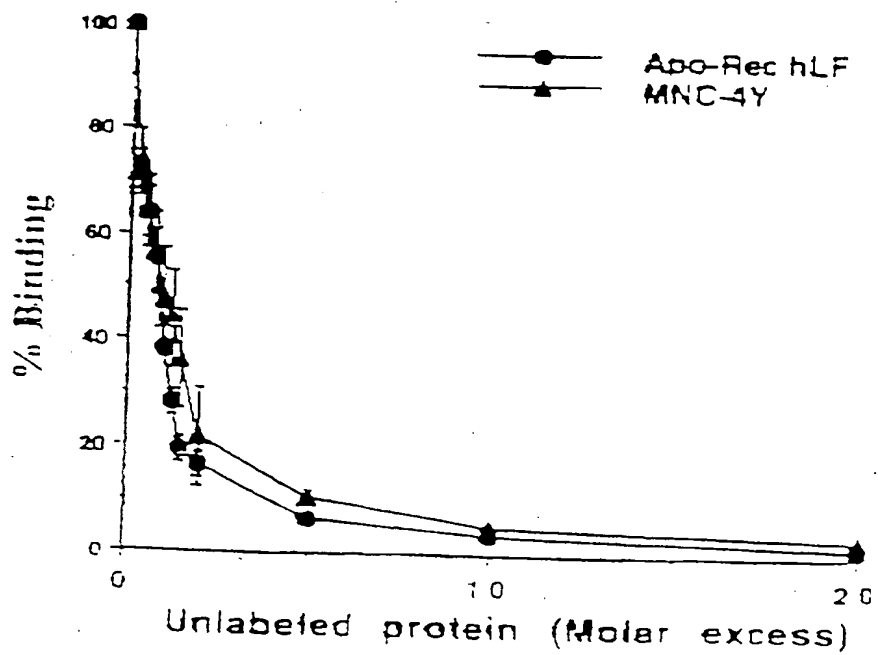


FIGURE 2C



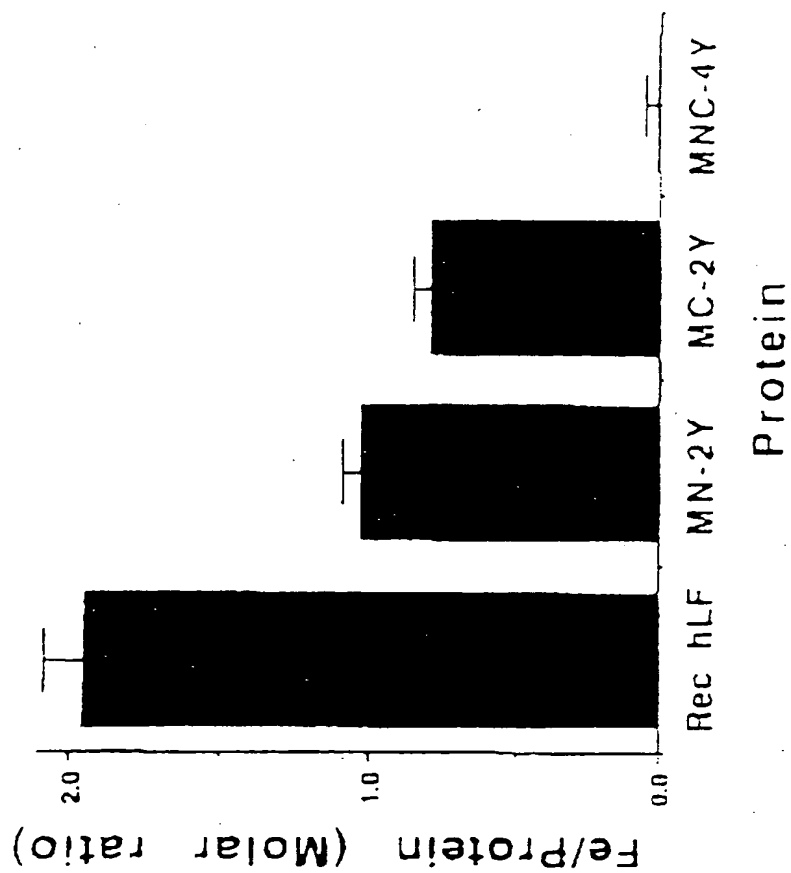
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FIGURE 2D



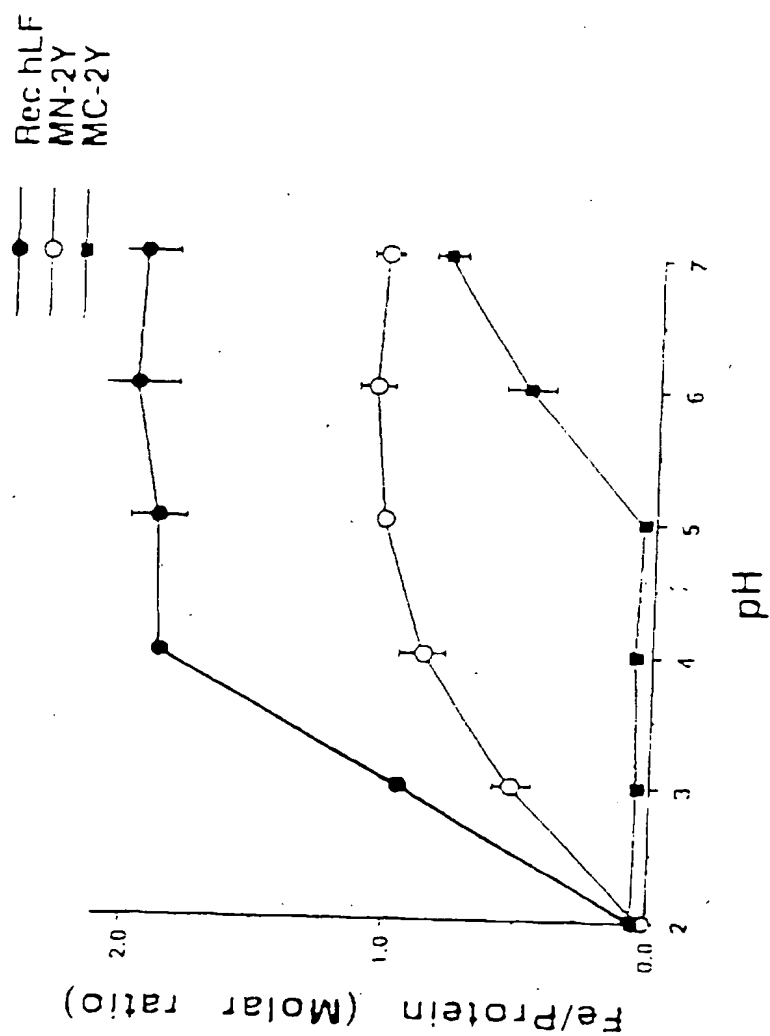
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FIGURE 3



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FIGURE 4



## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US97/09531

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(6) : A61K 38/40; C07K 14/79; C12N 15/12, 15/63, 15/79, 15/80, 15/85  
US CL : 514/6; 530/400; 435/69.1, 69.7, 172.3, 252.3, 254.3, 320.1, 325  
According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 514/6; 530/400; 435/69.1, 69.7, 172.3, 252.3, 254.3, 320.1, 325

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
Please See Extra Sheet.

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	TWEEDIE, J. W. et al. Lactoferrin cDNA Expression and In Vitro Mutagenesis. Advances in Experimental Medicine Biology. 1994, Vol. 357, pages 197-208, especially pages 202-207.	1, 3-5, 7, 8, 13 and 14 ----- 9
X --- Y	DAY, C. L. et al. Studies of the N-terminal Half of Human Lactoferrin Produced from the Cloned cDNA Demonstrate That Interlobe Interactions Modulate Iron Release. The Journal of Biological Chemistry. 15 July 1992, Vol. 267, No. 20, pages 13857-13862, especially pages 13859-13862.	1, 3-5, 7, 8, 13 and 14 ----- 9

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

Special categories of cited documents:			
*A*	document defining the general state of the art which is not considered to be of particular relevance	*T*	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
*E*	earliest document published on or after the international filing date	*X*	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
*L*	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*Y*	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
*O*	document referring to an oral disclosure, use, exhibition or other means		
*P*	document published prior to the international filing date but later than the priority date claimed	*A*	document member of the same patent family

Date of the actual completion of the international search 14 AUGUST 1997	Date of mailing of the international search report 26 SEP 1997
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer WILLIAM W. MOORE <i>William W. Moore</i> Telephone No. (703) 308-0196

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US97/09531

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WARD, P. P. et al. An inducible expression system for the production of human lactoferrin in <i>Aspergillus nidulans</i> . Gene. 01 December 1992, Vol. 122, pages 219-223, see entire article.	9
A	WO 91/13982 A1 (FERRODYNAMICS, INC.) 19 September 1991, pages 9-16.	1, 3-5, 7, 8, 13 and 14
A	DAY, C. L. et al. Structure of the Recombinant N-Terminal Lobe of Human Lactoferrin at 2.0 A Resolution. Journal of Molecular Biology. 05 August 1993, Vol. 232, pages 1084-1100.	14
A	SEYFERT, H.-M. et al. Lactoferrin: Interactions and Biological Functions. Totowa, NJ: Humana Press Inc., 1997, pages 61-79.	1, 3-5, 7, 8, 13 and 14
A	SHETH, B. et al. Cloning and Expression of the C-Terminal Lobe of Human Lactoferrin. Advances in Experimental Medicine and Biology. 1994, Vol. 357, pages 259-263.	1, 3-5, 7, 8, 13 and 14
A	LONNERDAL, B. et al. Lactoferrin: Molecular Structure and Biological Function. Annual Review of Nutrition. 1995, Vol. 15, pages 93-110.	14

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US97/09531

## B. FIELDS SEARCHED

Electronic data bases consulted (Name of data base and where practicable terms used):

DIALOG databases Medline, Current BioTech Abstracts, Derwent Biotechnology Abstracts, CA Search, Biosis Previews, Agricola, Derwent World Patent Index were searched. SEQ IDs NOs:4-7 and their inverse complements were searched in GenBank 99, GenBank-NEW 3, UEMBL 50-99, N-GeneSeq 26, GenBank-EST 99, GenBank-N-EST 3, and UEMBL-EST 50-99.





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<p>(21) International Application Number: <b>PCT/US97/09531</b>  (22) International Filing Date: 2 June 1997 (02.06.97)  (30) Priority Data:  <table border="0"> <tr> <td>60/018,747</td> <td>31 May 1996 (31.05.96)</td> <td>US</td> </tr> <tr> <td>08/866,544</td> <td>30 May 1997 (30.05.97)</td> <td>US</td> </tr> </table>  (71) Applicant: <b>BAYLOR COLLEGE OF MEDICINE [US/US];</b> One Baylor Plaza, Houston, TX 77030 (US).  (72) Inventors: <b>CONNELLY, Orla, M.;</b> 2601 South Braeswood #1307, Houston, TX 77025 (US). <b>WARD, Pauline, P.;</b> Baylor College of Medicine, Dept. of Cell Biology, One Baylor Plaza, Houston, TX 77030 (US).  (74) Agents: <b>ABRAMS, Samuel, B. et al.; Pennie &amp; Edmonds</b> <b>L.L.P.,</b> 1155 Avenue of the Americas, New York, NY 10036 (US). </p>		60/018,747	31 May 1996 (31.05.96)	US	08/866,544	30 May 1997 (30.05.97)	US	<p>(81) Designated States: <b>AU, CA, CN, IL, JP, KR, MX, NO, NZ, PL, RU, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).</b>  <b>Published</b> <i>With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i></p>
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<p>(54) Title: <b>LACTOFERRIN VARIANTS AND USES THEREOF</b>  (57) Abstract  The present invention is directed to recombinant nucleic acids encoding lactoferrin variants and portions thereof, having modified iron-binding capacity, and to vectors comprising same recombinant nucleic acids. The present invention is further directed to methods of producing such vectors, and to transfected cells harboring the same. Methods for the production of lactoferrin variants and portions thereof, in various eukaryotic or prokaryotic cells are also provided. Finally, the invention is directed to lactoferrin variants and portions thereof encoded by the nucleic acids of the invention and produced by the processes of the invention. Thus, the invention provides an efficient and economical means for the production of recombinant lactoferrin variants and portions thereof.</p>								

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## LACTOFERRIN VARIANTS AND USES THEREOF

### I. FIELD OF THE INVENTION

The present invention generally relates to lactoferrin related glycoproteins.

- 5 More specifically, the present invention relates to lactoferrin variants and portions thereof, their production and uses.

### II. BACKGROUND OF THE INVENTION

- Lactoferrin is a member of the transferrin family of non-heme iron binding glycoproteins (Aisen *et al.*, 1980, *Ann. Rev. Biochem.* 49:357-393), which includes transferrin, the major iron-transport protein in blood (MacGillivray *et al.*, 1983, *J. Biol. Chem.* 258:3543-3553), ovotransferrin, an avian egg white protein (Jeltsch *et al.*, 1982, *Eur. J. Biochem.* 122:291-295) and melanotransferrin, a membrane bound form of this family found in human melanocytes (Rose *et al.*, 1986, *Proc. Natl. Acad. Sci. USA* 83:1261-1265). Lactoferrin has a broad distribution, present in both external secretions that bathe the body surfaces (Masson *et al.*, 1971, *Comp. Biochem. Physiol.* 39:119-129; Hennart *et al.*, 1991, *Am. J. Clin. Nutr.* 53:32-39; Masson *et al.*, 1966, *Clin. Chim. Acta.* 14:735-739; Pentecost *et al.*, 1987, *J. Biol. Chem.* 262:10134-10139; Yu *et al.*, 1993, *Biochem. J.* 296:107-111) and in the secondary granules of polymorphonuclear neutrophils where it can be released into the bloodstream upon neutrophil activation (Masson *et al.*, 1969, *J. Exp. Med.* 130:643-658). The functions proposed for lactoferrin include iron binding and delivery to the small intestine (Fransson *et al.*, 1980, *J. Pediatrics* 96:380-384; Iyer *et al.*, 1993, *Eur. J. Clin. Nutr.* 47:232-241; Cox *et al.*, 1979, *Biochem. Biophys. Acta.* 558:129-141; Hu *et al.*, 1988, *Biochem. J.* 249:435-441; Gislason *et al.*, 1995, *J. Pediatr. Gastroent. Nutr.* 21:37-43; Mikogami *et al.*, 1994, *Am. J. Physiol.* 267:G1-G8; Ward *et al.*, 1995, *Biotechnology* 13:498-503), antimicrobial activity against a wide range of gram-negative and gram-positive bacteria (Oram *et al.*, 1968 *Biochem. Biophys. Acta.* 170:351-365; Arnold *et al.*, 1977, *Science* 197:263-265; Ellison *et al.*, 1988, *Infect. Immun.* 56:2774-2781; Bellamy *et al.*, 1992, *Biochem. Biophys. Acta.* 1221:130-136; Yamauchi *et al.*, 1993, *Infect. Immun.* 61:719-728), cellular growth promotion (Hashizume *et al.*, 1983, *Infect. Immun.* 763:377-382; Nichols *et al.* 1987, *Pediatr. Res.* 21:563-567), regulation of myelopoiesis (Sawatzki *et al.*, 1989, *Blood Cells* 15:371-375;

Broxmeyer *et al.*, 1986, *Blood Cells* 13:31-48; Zucali *et al.*, 1979, *Blood* 54:951-954), and immunomodulatory properties (Machnicki *et al.*, 1993, *Int. J. Exp. Path.* 74:433-439; Crouch *et al.*, 1992, *Blood* 80:235-240; Zagulski *et al.*, 1989, *Br. J. Exp. Pathol.* 70:697-704).

5 Lactoferrin shares a high degree of structural homology with other members of the transferrin family. All of these proteins are monomeric glycoproteins with a molecular weight of ~80 kDa. Aisen *et al.*, 1980, *Ann. Rev. Biochem.* 49:357-393; Metz-Boutique *et al.*, 1984, *Eur. J. Biochem.* 145:659-676. The three dimensional structure of lactoferrin (Anderson *et al.*, 1989, *J. Mol. Biol.* 209:711-10 734) and transferrin (Lindley *et al.*, 1988, *Biochem.* 27:5804-5812) have been precisely defined by X-ray crystallographic analysis. The proteins are folded into two globular lobes corresponding to the amino- and carboxy-terminal halves of the protein. This bilobal structure, with ~40% conservation between the amino- and carboxy-terminal halves, is thought have evolved by intragenic duplication from a common ancestral gene. Williams *et al.*, 1982, *Trends Biochem. Sci.* 7:394-397. 15 Each of these lobes can reversibly bind iron with high affinity and with the concomitant binding of an anion, usually carbonate. Aisen *et al.*, 1980, *Ann. Rev. Biochem.* 49:357-393. The amino acids required for iron binding by lactoferrin are highly conserved between members of the transferrin family. Baker *et al.*, 20 1992, *J. Inorg. Biochem.* 47:147-160. In lactoferrin, an iron atom binds to Asp 396, Tyr 93, Tyr 193 and His 254 in the amino-terminal lobe, and the corresponding Asp 396, Tyr 436, Tyr 539 and His 598 in the carboxy-terminal lobe, respectively. Anderson *et al.*, 1989, *J. Mol. Biol.* 209:711-734.

Nonwithstanding their structural similarities, lactoferrin displays much more 25 avid iron binding properties than its serum counterpart, transferrin. In particular, the release of iron from lactoferrin displays greater pH stability than transferrin, the latter releasing iron in a pH range of about six (6) to about four (4) while the former releases iron a pH range of about four (4) to about two (2). Mazurier *et al.*, 1989, *Biochem. Biophys. Acta.* 629:399-408. It has been suggested that the unique 30 iron binding properties of lactoferrin contribute to some of the diverse functional activities proposed for this protein. Elucidation of the structural and functional features involved in the unique iron binding properties of lactoferrin will allow the modelling and generation of lactoferrin variants with improved properties,

including, but not limited to, lactoferrin variants with higher affinity for iron for improved antimicrobial activities, lactoferrin variants with lower affinity for iron having improved iron releasing properties, or lactoferrin variants having modified pH dependent efficiencies for iron release.

5           The Applicants of the present invention have previously reported the high level production and characterization of recombinant human lactoferrin in the filamentous fungi, including *Aspergillus*. Ward *et al.*, 1995, *Biotechnology* 13:498-503; U.S. Patent Nos. 5,571,896, 5,571,619, and 5,571,697, incorporated by reference in their entirety. Nonwithstanding its distinct and unique  
10 carbohydrate composition, the recombinant protein was shown to be indistinguishable from human breast milk lactoferrin with respect to its physiological activities, including iron and receptor binding and antimicrobial activity. Hence, the availability of this expression system provides now the production of lactoferrin variants in sufficient quantities to address the  
15 structure/function role of this protein, in order to generate variants with improved properties.

### III. SUMMARY OF THE INVENTION

          The present invention relates to nucleic acid sequences encoding lactoferrin  
20 variants or portions thereof, wherein the portion comprises a sequence corresponding to at least one iron binding site of lactoferrin. The lactoferrin variant or portion thereof is further defined by having a modified iron binding capacity when compared to *wild-type* lactoferrin.

          Using site-directed mutagenesis, the present invention elucidates the  
25 contribution of the two-lobe structure to the unique iron binding properties of lactoferrin. Human lactoferrin cDNA was selectively mutated in the two tyrosine residues involved in iron binding in either or both halves of the protein. The resulting three iron binding defective variants were expressed in and purified from *Aspergillus awamori*. Iron binding analysis using  $^{59}\text{FeCl}_3$  confirmed that mutation  
30 of the two tyrosine residues involved in iron binding in either lobe, resulted in selective loss of iron binding to the mutated lobe. In addition, pH dependent iron-release studies demonstrated a differential iron binding stability of the two halves of lactoferrin, the amino-terminal lobe being much more acid-labile than the

carboxy-terminal lobe. More importantly, the present invention shows that a functional iron binding carboxy-terminal lobe is necessary for the pH stability of iron binding to the amino-terminal lobe which is characteristic of *wild-type* lactoferrin. These results support the conclusion that cooperative interactions  
5 between the two lobes of lactoferrin contribute to the unique iron binding properties of this protein.

Thus, the present invention provides guidance for the generation of lactoferrin variants having improved properties, such as modified iron binding characteristics, *e.g.*, increased or decreased affinity for iron, or modified pH or  
10 temperature requirements or ranges for iron binding. Furthermore, the present invention provides guidance for the modelling of lactoferrin variants having otherwise improved characteristics, *e.g.*, therapeutic tolerance, while retaining their iron binding activity.

In a second aspect, the present invention is further directed to vectors  
15 comprising nucleic acids encoding lactoferrin variants or portions thereof, suitable for expression of the lactoferrin variant or portion thereof in eukaryotic cells. Preferably, the plasmid are suitable for expression in fungal cells, including *Aspergillus oryzae*, *Aspergillus niger*, *Aspergillus nidulans* and *Aspergillus awamori*.

20 In a third aspect, the present invention is further directed to methods of producing such vectors, and to transfected cells harboring the same. Methods for the production of lactoferrin and variants thereof in various eukaryotic or prokaryotic cells are also provided. Finally, the invention is directed to lactoferrins and variants thereof produced by the processes of the invention. Thus,  
25 the invention provides an efficient and economical means for the production of recombinant lactoferrin protein and variants thereof, and lactoferrin related polypeptides.

#### IV. BRIEF DESCRIPTION OF THE DRAWINGS

FIGURES 1A and 1B depict a Western immunoblot and silver stain analysis of the purified iron binding defective lactoferrin variants.

FIGURE 1A depicts a Western immunoblot analysis of 200 ng samples of purified recombinant human lactoferrin (Rec hLF), amino-terminal (MN-2Y), carboxy-terminal (MC-2Y) and amino- and carboxy-terminal (MNC-4Y) iron binding defective variants of lactoferrin, respectively.

FIGURE 1B depicts a Silver-stained SDS-polyacrylamide gel analysis of purified Rec hLF, MN-2Y, MC-2Y and MNC-4Y (1  $\mu$ g each).

FIGURES 2A, 2B, 2C, and 2D depict competition of biotinylated recombinant lactoferrin binding to human enterocyte cells by the iron binding defective lactoferrin variants.

FIGURE 2A. Iron-saturated biotinylated recombinant human lactoferrin (0.4  $\mu$ M) was incubated with Caco-2 membranes (300 ng) in the presence or absence of increasing concentrations of unlabeled iron-saturated recombinant lactoferrin (Fe-RechLF) or apo-recombinant lactoferrin (Apo-RechLF). Inhibition of biotinylated lactoferrin binding to Caco-2 membranes was determined using a biotin/avidin microtiter assay (Ward *et al.*, 1995, *Biotechnology* 13:498-503).

FIGURES 2B, 2C, and 2D. Apobiotinylated recombinant human lactoferrin (0.4  $\mu$ M) was incubated with Caco-2 membranes (300 ng) in the presence or absence of increasing concentrations of unlabeled Apo-RechLF or MN-2Y (FIGURE 2B), MC-2Y (FIGURE 2C) or MNC-4Y (FIGURE 2D). Inhibition of biotinylated lactoferrin binding to Caco-2 membranes was determined using a biotin/avidin-microtiter assay. The data are represented as means  $\pm$  S.E.M.

FIGURE 3 depicts iron-saturation analysis of the lactoferrin amino-terminal (MN-2Y), carboxy-terminal (MC-2Y) and amino- and carboxy-terminal (MNC-4Y) iron binding defective variants. Iron-free recombinant human lactoferrin (Rec hLF), MN-2Y, MC-2Y, and MNC-4Y were saturated with iron as described in the experimental procedures.  $^{59}$ Fe bound to the samples was quantified using liquid scintillation counting and the Fe/protein molar ratios were determined. The data are represented as means  $\pm$  S.E.M.

FIGURE 4 depicts pH-dependent release of  $^{59}$ Fe from the lactoferrin amino-terminal (MN-2Y) and carboxy-terminal (MC-2Y) iron binding defective variants.

<sup>59</sup>Fe-saturated recombinant human lactoferrin (Rec hLF), MN-2Y and MC-2Y were dialyzed against buffers ranging in pH from 7-2. <sup>59</sup>Fe remaining bound to the lactoferrin samples after dialysis was quantified by liquid scintillation counting and the Fe/protein molar ratio was determined. The data are represented as means +/- S.E.M.

## V. DEFINITIONS

Terms used herein are in general as typically used in the art. The following terms are intended to have the following general meanings as they are used herein:

10 The term "*lactoferrin variant*" refers to a polypeptide generated by mutation of a naturally occurring lactoferrin in at least one amino acid position.

The term "*vector*" means plasmid, cosmid, phage, virus, retrovirus or other vehicle to allow insertion, propagation and/or expression of a nucleic acid encoding a lactoferrin variant or portion thereof.

15 The term "*host cell*" means any cell that will allow lactoferrin expression.

The term "*promotor*" means regulatory DNA sequences that controls transcription of the lactoferrin cDNA.

The term "*transformation*" means incorporation permitting expression of heterologous nucleic acid sequences by a cell.

20 The term "*iron binding capacity*" means ability to bind Fe. Fully functional human lactoferrin can bind two atoms of iron per molecule of lactoferrin.

The term "*biological activity/biological active*" means biological activity of lactoferrin as measured by its ability to bind iron, or kill microorganisms, or retard the growth of microorganisms, or to function as an iron transfer protein.

## VI. DETAILED DESCRIPTION OF THE INVENTION

### A. Overview

30 The present invention is based, in part, on the identification those domains, sequences, and structures in the lactoferrin polypeptide which contribute to the iron binding capacity/properties of the protein. As such, the present invention provides guidance for the generation of lactoferrin variants having improved characteristics, such as modified iron binding characteristics, *e.g.*,



increased or decreased iron binding capacity, or modified pH or temperature requirements or ranges for the binding of iron. Furthermore, the present invention provides guidance for the modelling of lactoferrin variants having otherwise improved characteristics, *e.g.*, therapeutic tolerance, stability against degradation,  
5 or immunoreactivity, while retaining their iron binding activity.

Accordingly, the present invention is directed to recombinant nucleic acids encoding lactoferrins variants and portions thereof, and to vectors comprising same recombinant nucleic acids. The present invention is further directed to methods of producing such vectors, and to transfected cells harboring the same. Methods for  
10 the production of lactoferrin variants and portions thereof in various eukaryotic or prokaryotic cells are also provided. Finally, the invention is directed to lactoferrins variants and portions thereof encoded by the nucleic acids of the invention and/or produced by the processes of the invention. Thus, the invention provides guidance for the design of lactoferrin variants or portions thereof having  
15 improved characteristics, and an efficient and economical means for the production of such lactoferrin variants and portions thereof.

#### **B. Contribution Of The Bilobal Structure Of Lactoferrin To Its Unique Iron Binding Properties**

20 In the present invention, a site-directed mutagenesis approach was used to investigate the contribution of the bilobal structure of lactoferrin to the unique iron binding properties of this protein.

More specifically, the two tyrosines involved in iron binding in either or both lobes of lactoferrin were mutated to corresponding alanine residues in order to  
25 produce three iron binding defective variants. These lactoferrin variants were expressed and purified from *A. awamori* as previously described for the *wild-type* protein. U.S. Patent No. 5,571,896; Ward *et al.*, 1995, *Biotechnology* 13:498-503. The size, immunoreactivity and functional activity of these lactoferrin variants as determined by silverstain, western immunoblotting and enteric receptor  
30 binding analysis were similar to *wild-type* recombinant human lactoferrin indicating that the amino-acid substitutions had no adverse effect on the protein. Iron-saturation analysis using  $^{59}\text{FeCl}_3$  showed that while the lactoferrin variant with an intact carboxy-terminal iron binding lobe saturate at the expected 1:1 ratio of iron

to protein, the variant with an intact amino-terminal iron binding function consistently saturated at less than 1:1 suggesting a reduced stability of iron binding of this lactoferrin variant at pH 7.0. In addition, iron binding studies demonstrated that mutation of the tyrosine residues in both lobes effectively disrupted the iron binding capacity of the complete protein. See, Sections VII.A., VII.C., and VII.D.

As disclosed herein, pH dependent iron-release studies from the non-mutated lobes showed that the stability of iron binding to the amino- and carboxy-terminal lobes of lactoferrin were dissimilar. The release of iron from the lactoferrin variant containing an intact carboxy-terminal iron binding function was similar to that observed for the native lactoferrin. In contrast, the lactoferrin variant with an intact amino-terminal iron binding site was much more acid-labile, releasing all of its bound iron between a pH of 7-5. Hence, despite the overall structural homology between these two lobes (40%), it is demonstrated that the amino- and carboxy-terminal lobes of lactoferrin differ in their pH stability of iron binding. Furthermore, it is demonstrated that a functional iron binding carboxy-terminal lobe is required to impart the iron binding stability to the amino-terminal lobe which is characteristic of the *wild-type* protein.

The non-equivalence of iron binding to the amino and carboxy terminal lobes of lactoferrin has been reported previously. Mazurier *et al.*, 1989, *Biochem. Biophys. Acta.* 629:399-408; Day *et al.*, 1992, *J. Biol. Chem.* 167:13857-13862; Shimazaki *et al.*, 1993, *J. Dairy Sci.* 76:946-955. Studies using a cloned amino-terminal fragment of human lactoferrin (Day *et al.*, 1992, *J. Biol. Chem.* 167:13857-13862) and a proteolytically derived carboxy-terminal fragment from bovine lactoferrin (Shimazaki *et al.*, 1993, *J. Dairy Sci.* 76:946-955) have shown a similar disparity in pH dependence of iron binding as reported in the present invention. However, while the previous reports did indicate that the carboxy-terminal lobe, or part thereof, was required to stabilize the amino-terminal lobe iron binding function, these studies were limited as it remained to be determined whether the structural presence of the carboxy-terminal lobe or a functional carboxy-terminal iron binding activity was required for stabilization of iron binding to the amino-terminal lobe. The present invention extends these studies and show that cooperative interactions, driven primarily by a functional carboxy-terminal lobe are necessary for iron binding stabilization.

The bias for selection of a bilobal structure in the evolution of the transferrin family is unknown. The instant disclosure provides a functional rationale for this selection in the case of lactoferrin. As such, the present invention shows that the evolution of a two lobe structure has endowed lactoferrin with  
5 unique iron binding properties which are likely to impinge on the unique functional activity of this protein. Interestingly, transferrin differs from lactoferrin in that it has been shown that the pH dependent iron release properties of this protein and a proteolytically derived amino-terminal fragment are similar. Mazuier *et al.*, 1989, *Biochem. Biophys. Acta.* 629:399-408; Lineback-Zins *et al.*, 1980, *J. Biol. Chem.*  
10 255:708-713. These findings may suggest that a lack of cooperativity between the two lobes of transferrin may be a critical factor accounting for the characteristically weaker iron binding stability of this protein. Taken together with the studies described herein, it is suggested that the different iron binding properties of lactoferrin and transferrin may be due, at least in part, to the evolution of a  
15 carboxy terminal iron binding lobe of lactoferrin that has increased acid stability and functions cooperatively with the amino-terminal lobe to confer a pH stability to this lobe that is characteristic of the bilobal protein.

### C. Lactoferrin Variants

20 Based on its identification of those domains, sequences and structures in the lactoferrin polypeptide contributing to the iron binding properties of the protein, the present invention provides guidance for the design and generation of novel lactoferrin variants or portions thereof having a modified iron binding capacity. Typically, the lactoferrin variants of the invention have  
25 improved properties, including, but not limited to, lactoferrin variants with higher affinity for iron for improved antimicrobial activities, lactoferrin variants with lower affinity for iron having improved iron-releasing properties, or lactoferrin variants having modified pH or temperature requirements or ranges for the binding and/or release of iron. In addition, the invention allows for the design of  
30 lactoferrin variants having otherwise improved characteristics, *e.g.*, therapeutic tolerance, immunoreactivity, or biological half life, while retaining their iron binding capacity.

The lactoferrin variants of the invention may be derived from *wild-type* lactoferrin of a variety of mammalian species, including, but not limited to, human, murine, rat, bovine, and porcine lactoferrin. The *wild-type* lactoferrin may be mutated by a variety of methods generally known in the art. See, among other  
5 places, Sambrook *et al.*, 1990, *Molecular Cloning: A Laboratory Manual*. Cold Spring Harbour Laboratory Press, New York; Kunkel *et al.*, 1987, *Meth. Enzymol.* 154:367-382; Kunkel, 1985, *Proc. Natl. Acad. Sci. USA* 82:488-492.

In a preferred embodiment, the lactoferrin variant comprises at least one mutation affecting at least one iron binding site. Such iron binding site may have  
10 modified iron binding characteristics when compared to *wild-type* lactoferrin. For example, affinity for iron may increased or decreased. In addition, affinity for iron may exhibit modified pH range characteristics. Alternatively, the iron binding site may be modified such that the lactoferrin variant or portion thereof does not bind iron at all.

15 In another embodiment, the lactoferrin variant does comprise at least one mutation effecting modification of the therapeutic tolerance, biological stability or immunotolerance of lactoferrin, while retaining its biological activity.

#### D. Expression And Production Of Lactoferrin Variants

20 The nucleic acid sequences of the invention encoding lactoferrin variants may be inserted in a vector suitable for its expression in a eukaryotic cell in such way that allows expression of the lactoferrin variant. Alternatively, nucleic acid sequences encoding portions of the lactoferrin variants of the invention may be inserted in vectors allowing their expression in eukaryotic cells. Preferably, the  
25 portion of the lactoferrin variant comprises at least one iron binding site, which may be modified.

In preferred embodiment, lactoferrin is produced in recombinant expression systems. See, among other places, Ward *et al.*, 1992, *Biotechnology* 10:784-789; Ward *et al.*, 1995, *Biotechnology* 13:498-503. For this purpose, nucleic acids  
30 coding for the desired form of lactoferrin (*see, e.g.*, U.S. Patent 5,571,691, incorporated by reference in its entity) is incorporated expressibly in a cellular host, which is then cultured under conditions appropriate for expression of that particular peptide or protein. A variety of gene expression systems have been

adapted for this purpose, and typically drive expression of the desired gene from expression controls used naturally by the chosen host.

Because the lactoferrin variants of the invention typically, as natural occurring lactoferrin, requires post-translational modifications, such as glycosylation at several amino acid residues, many of the lactoferrins variants or portions thereof need to be produced in an eukaryotic host. In preferred embodiments, the lactoferrin product is produced by an *Aspergillus* expression system, as described in Ward *et al.*, 1992, *Gene* 122:219-223; and U.S. Patent Nos. 5,571,896 and 5,571,697, incorporated by reference in its entirety.

If unglycosylated forms of lactoferrin variants or portions thereof are produced, however, their production may conveniently be achieved in bacterial hosts such as *E. coli*. For such production, nucleic acid coding for the selected lactoferrin variant or portion thereof, may usefully be placed under an expression control, *e.g.*, of the lac, trp or PL genes of *E. coli*.

As an alternative to expression of nucleic acid coding for the lactoferrin variant or portion thereof *per se*, the host can be adapted to express the lactoferrin product as a fusion protein in which the lactoferrin product is linked releasably to a carrier protein that facilitates isolation and stability of the expression product.

In a further alternative, the lactoferrin variant or portion thereof may be generated by organic synthesis. In particular where production of a portion of a lactoferrin variant, *e.g.*, a peptide of about twenty (20) through about fifty (50) amino acids in length, is the objective preferably the well established techniques of automated peptide synthesis are employed, general descriptions of which appear, for example, in J.M. Stewart and J.D. Young, Solid Phase Peptide Synthesis, 2nd Edition, 1984, Pierce Chemical Company, Rockford, Illinois; and in M. Bodanszky and A. Bodanszky, The Practice of Peptide Synthesis, 1984, Springer-Verlag, New York; Applied Biosystems 430A Users Manual, 1987, ABI Inc., Foster City, California; and Solid Phase Peptide Synthesis - A Practical Approach, by: E. Atherton & R.C. Sheppard, IRL Press, Oxford (1989). In these techniques, the lactoferrin variant portion is grown from its C-terminal, resin-conjugated residue by the sequential addition of appropriately protected amino acids, using either the Fmoc or tBoc protocols.

### **E. Applications**

The lactoferrin variants of the present invention may be used for a broad variety of applications.

For example, a lactoferrin variant or portion thereof having improved iron  
5 binding capacity may be used for antimicrobial applications, including the treatment of infections, as additive to human or animal foods, as additive for eyedrops, eardrops, contact lense and other eye care solutions, topical skin care products, mouthwashes, chewing gum and toothpaste.

Lactoferrin variants or portions thereof having modified pH or temperature  
10 requirements may also be useful for the above applications. They further may be used as therapeutic additives for enhanced or modified iron transport and delivery.

Other applications of lactoferrin variants and portions thereof include the treatment of inflammatory skin diseases, as described in the co-pending provisional application, identified as Attorney Docket Number 8206-041-888, filed April 10,  
15 1997, hereby incorporated by reference in its entirety.

For many of the above identified applications, which are only to be understood as examples, lactoferrin variants and portions thereof having improved therapeutic tolerance, modified biological stability, or immunotolerance, may be particularly preferred.

20

### **F. Pharmaceutical Formulation And Routes Of Administration**

For therapeutic use, the lactoferrin variants or portions thereof chosen can be administered by any conventional means available for use in conjunction with pharmaceuticals, either as individual therapeutic agents or in a  
25 combination of therapeutic agents. Each can be administered alone but is generally administered with a pharmaceutical carrier selected on the basis of the chosen route of administration and standard pharmaceutical practice. The pharmaceutical compositions of the invention may be adapted for oral, parenteral, topical or rectal administration, or as inhalant, and may be in unit dosage form, in a manner well  
30 known to those skilled in the pharmaceutical art. Parenteral administration includes but is not limited to, injection subcutaneously, intravenously, intraperitoneally or intramuscularly.

Treatment with the active ingredient may begin at any time after the indication to be treated, *e.g.*, infections, or skin disorders, *e.g.*, psoriasis, contact dermatitis, UV-induced inflammation, infant diaper rash, asthma, arthritis, and the like, is diagnosed. Preferably, treatment is commenced as a prophylactic or at  
5 early stages of the disease, in order to prevent massive infection or inflammation in the first place. Typically, treatment will continue until the disorder is cured. In cases of chronic diseases, such as psoriasis, asthma or arthritis, or in cases of continued exposure to an allergen, the treatment may have to be extended beyond the cure of the symptoms.

10 The dose administered will, of course, vary depending upon known factors, such as (1) the pharmacodynamic characteristics of the particular lactoferrin product and its mode and route of administration, (2) the age, health, height and weight of the recipient, (3) the nature and extent of the symptoms, (4) the kind of concurrent treatment(s), (5) the frequency of treatment(s), and (6) the effect  
15 desired. A daily dose of active ingredient can be determined by those skilled in the art depending on the above factors.

The active ingredient may be administered topically, as inhalant, or as injection, *e.g.*, in inflamed joints or cartilage. However, alternatively the lactoferrin variant may be administered orally in solid or semi-solid dosage forms,  
20 such as hard or soft-gelatin capsules, tablets, or powders, or in liquid dosage forms, such as elixirs, syrups, or suspensions. It can also be administered parenterally, in sterile liquid dosage forms. Other dosage forms are potentially possible such as patches or ointment or transdermal administration.

The lactoferrin variants of the invention may also be formulated as a slow  
25 release implantation device for extended and sustained administration of the lactoferrin product. Examples of such sustained release formulations include composites of biocompatible polymers, such as poly(lactic acid), poly(lactic-co-glycolic acid), methylcellulose, hyaluronic acid, collagen, and the like. The structure, selection and use of degradable polymers in drug delivery vehicles have  
30 been reviewed in several publications, including, A. Domb *et al.*, Polymers for Advanced Technologies 3:279-292 (1992). Additional guidance in selecting and using polymers in pharmaceutical formulations can be found in the text by M. Chasin and R. Langer (eds.), "Biodegradable Polymers as Drug Delivery Systems,

" Vol. 45 of "Drugs and the Pharmaceutical Sciences," M. Dekker, New York, 1990. Liposomes may also be used to provide for the sustained release of a lactoferrin variant or portion thereof. Details concerning how to use and make liposomal formulations of drugs of interest can be found in, among other places, 5 U.S. Pat. No 4,944,948; U.S. Pat. No. 5,008,050; U.S. Pat. No. 4,921,706; U.S. Pat. No. 4,927,637; U.S. Pat. No. 4,452,747; U.S. Pat. No. 4,016,100; U.S. Pat. No. 4,311,712; U.S. Pat. No. 4,370,349; U.S. Pat. No. 4,372,949; U.S. Pat. No. 4,529,561; U.S. Pat. No. 5,009,956; U.S. Pat. No. 4,725,442; U.S. Pat. No. 4,737,323; U.S. Pat. No. 4,920,016. Sustained release formulations are of 10 particular interest when it is desirable to provide a high local concentration of a lactoferrin variant, *e.g.*, in arthritic joints, or at local skin inflammations, etc.

Gelatin capsules or liquid-filled soft gelatin capsules may contain the active ingredient and powdered or liquid carriers, such as lactose, lecithin starch, cellulose derivatives, magnesium stearate, stearic acid, and the like. Similar 15 diluents can be used to make compressed tablets. Both tablets and capsules can be manufactured as sustained release products to provide for continuous release of medication over a period of hours. Compressed tablets can be sugar-coated or film-coated to mask any unpleasant taste and to protect the tablet from the atmosphere, or enteric-coated for selective disintegration in the gastrointestinal 20 tract. Liquid dosage forms for oral administration can contain coloring and/or flavoring to increase patient acceptance.

Suitable pharmaceutical carriers are further described in Remington's Pharmaceutical Sciences, 17th ed., Mack Publishing Company, Easton, PA (1990) a standard reference text in this field, which is incorporated herein by reference in 25 its entirety.

The below examples explain the invention in more detail. The following preparations and examples are given to enable those skilled in the art to more clearly understand and to practice the present invention. The present invention, 30 however, is not limited in scope by the exemplified embodiments, which are intended as illustrations of single aspects of the invention only, and methods which are functionally equivalent are within the scope of the invention. Indeed, various modifications of the invention in addition to those described herein will become



apparent to those skilled in the art from the foregoing description and accompanying drawings. Such modifications are intended to fall within the scope of the appended claims.

## 5 VII. EXAMPLES

### A. Materials And Methods

**Construction Of pPLF-26, A Universal *Aspergillus Awamori* Expression Vector.** The construction of an expression vector, pPLF-19, for production of lactoferrin in *A. awamori* has previously been described. Ward *et al.*, 1995, *Biotechnology* 13:498-503; U.S. Patent No. 5,571,896. In order to construct an expression vector containing unique sites for cloning cDNAs encoding lactoferrin variants, pPLF-26 was generated. Briefly, pPLF-18 (Ward *et al.*, 1995, *Biotechnology* 13:498-503) was digested with SphI generating two fragments of 3.3 kb and 4.4 kb. The 3.3 kb SphI fragment containing the lactoferrin cDNA was subcloned into SphI digested pALTER (Promega, Madison, WI) generating pLF18sp.Alt. The 4.4 kb SphI fragment was relegated generating PR18.2. *In vitro* mutagenesis using the commercially available pALTER kit (Promega, Madison, WI) was used to introduce a NotI restriction enzyme site at the start of mature lactoferrin cDNA in pLF18Sp.Alt generating pNot.9. The 5' phosphorylated oligonucleotide used for the mutagenesis was as follows: 5' AGCGCGGCCCGCAGGAGAAGGA 3' [SEQ ID NO:1]. PR18.2 was digested with EcoRI and the resulting two fragments were repaired using the Klenow fragment of DNA polymerase I and religated in the correct orientation. The resulting plasmid, p $\Delta$ E12, was digested with SphI and ligated with a 3.3 kb SphI fragment from pNot.9 generating pPLF-25. PLO3, encoding the phleomycin resistance gene under the control of the  $\beta$ -tubulin promoter (Gatignol *et al.*, 1987, *Mol. Gen. Genet.* 207:342-348) was digested with EcoRI and the resulting fragments were repaired using the Klenow fragment of DNA polymerase I and religated in the correct orientation. The resulting vector, PLO3 $\Delta$ R1, was digested with *Hind*III and the resulting 2.3 kb fragment was subcloned into *Hind*III digested pPLF-25 in the same orientation as the lactoferrin cDNA generating pPLF-26.

**Constructing Of Iron Binding Defective Variants Of Lactoferrin, MN-2Y, MC-2Y And MNC-4Y.** Synthetic 5' phosphorylated oligonucleotides with

EcoRI/BamHI ends, were generated in order to introduce a NotI site into pALTER. The sequence of the oligonucleotides were as follows. Top strand 5'GATCCATGCGGCCGCATG 3' [SEQ ID NO:2]. Bottom strand: 5'AATTCATGCGGCCGCATG 3' [SEQ ID NO:3]. The oligonucleotides were  
5 annealed and ligated into EcoRI/BamHI digested pALTER generating pALTLink. pPLF-26 was digested with NotI/EcoRI and the resulting 2.1 kb fragment containing the human lactoferrin cDNA was subcloned into NotI/EcoRI digested pALTLink. The resulting plasmid, pALThLF was used for subsequent  
10 mutagenesis experiments. The tyrosine residues involved in iron binding by lactoferrin in the amino-terminal lobe (Tyr 93, Tyr 193), carboxy-terminal lobe (Tyr 436, Tyr 529 and amino- and carboxy-terminal lobes (Tyr 93, Tyr 193, Tyr 436 and Tyr 529) were converted to corresponding alanine residues using *in vitro* mutagenesis using the pALTER kit. The 5' phosphorylated oligonucleotides used for the mutagenesis were as follows.

15

Tyr 93 → Ala 93: 5' CACAGCCACGGCATAAGCGTGAGTTCGTGGCTG 3' [SEQ ID NO:4];

TYR 193 → Ala 193: 5' CTTGAAGGCACACAGAGGCGCTGAAGTACGGTTC 3' [SEQ ID NO:5];

20 Tyr 436 → Ala 436: 5' CACCGCCACAGCAAGGGCTCCTTCCACAGGTCT 3' [SEQ ID NO:6];

Tyr 529 → Ala 529: 5' CCGGAAAGCCCCAGTGGCGCCGTAGTATCTCTC 3' [SEQ ID NO:7].

25 The resulting plasmids, pALTMN-2Y, pALTMC-2Y, and pALTMNC-4Y, were digested with NotI/EcoRI and subcloned into NotI/EcoRI digested pPLF-26 generating expression plasmids suitable for expression of lactoferrin in *Aspergillus* fungal cells, *i.e.*, p26MN-2Y, p26MC-2Y and p26MNC-4Y, respectively. All oligonucleotides sequences and construction junction were sequenced using the  
30 commercially available Sequenase Version 2.0 kit (United States Biochemical Corporation, Cleveland OH).

***Expression And Purification Of MN-2Y, MC-2Y And MNC-4Y.*** The *A. awamori* expression vectors, p26MN-2Y, p26MC-2Y and p26MNC-4Y were

transformed into *A. awamori* and transformants obtained were cultured for 7 days as previously described. Ward *et al.*, 1995, *Biotechnology* 13:498-503. The culture medium was screened for the iron binding variants using an ELISA assay. Vilja *et al.*, 1985, *J. Immunol. Meth.* 76:73-83. Positive cultures (> 50 mg/l) were  
5 cultured in 2 liter flasks for 7 days and the lactoferrin variant was purified using ion-exchange chromatography using CM-sephadex. Ward *et al.*, 1995, *Biotechnology* 13:498-503. The proteins were dialyzed against 0.1 M citric acid followed by extensive dialysis against H<sub>2</sub>O and 5 mM sodium phosphate, pH 7.5 (3 g).

10 **Receptor Binding Assays.** Receptor binding assays were performed using a biotin/avidin microliter plate assay (Rejman *et al.*, 1994, *Int. J. Biochem.* 26:201-206) using 8 day old Caco-2 solubilized membranes (300 ng) essentially as described. Ward *et al.*, 1995, *Biotechnology* 13:498-503.

***Iron-Saturation And PH Stability Of Iron Binding To The Lactoferrin***

15 **Variants.** MN-2Y, MC-2Y and MNC-4Y (5 mg) were incubated with a four-fold excess of FeCl<sub>3</sub>:<sup>59</sup>FeCl<sub>3</sub>:NTA (400:1:8). Ward *et al.*, 1995, *Biotechnology* 13:498-503. The samples were incubated at room temperature for 30 minutes. The samples were purified through NAP-10 column (Pharmacia, Piscataway, NJ) followed by dialysis against 0.05 M Tris/HCl, 0.2 M NaCl, pH 7.0 for 12 hours to  
20 remove any non-specific iron bound to the lactoferrin variants. Iron bound to the lactoferrin variants after dialysis was quantified by liquid scintillation counting. The pH stability of iron binding for each of the lactoferrin variants was carried out as described previously. Ward *et al.*, 1995, *Biotechnology* 13:498-503.

25 **B. Example 1: Expression And Purification Of Iron Binding Defective Variants In The Amino And Carboxy-Terminal Domains Of Lactoferrin**

In order to examine the contribution of the two-domain structure to the unique iron binding properties of lactoferrin, a site-directed mutagenesis  
30 approach was used to generate mutations in the human lactoferrin cDNA which encoded proteins which were defective in iron binding in either or both lobes of the protein.

Specifically, Tyr 93, Tyr 193 were mutated to Ala 93, Ala 193 generating a variant unable to bind iron in the amino-terminal half of lactoferrin (MN-2Y). The corresponding tyrosine residues in the carboxy-terminal half of lactoferrin Tyr 436, Tyr 529 were converted to alanine residues resulting in inactivation of the iron binding function of the carboxy-terminal domain (MC-2Y). All four tyrosine residues involved in iron binding by lactoferrin, *i.e.*, Tyr 93, Tyr 193, Tyr 436 and Tyr 529, were also mutated to corresponding alanine residues generating a variant which was unable to bind iron in both lobes of lactoferrin (MNC-4Y).

The lactoferrin variants were expressed and purified from *A. awamori* as previously described for recombinant human lactoferrin. Ward *et al.*, 1995, *Biotechnology* 13:498-503, U.S. Patent No. 5,571,896. The purified proteins were subjected to polyacrylamide gel electrophoresis followed by either western immunoblot analysis or silver stain analysis. See, FIGURE 1. Western immunoblot analysis using a specific polyclonal IgG directed against human lactoferrin detected an immunoreactive band corresponding to the size of *wild-type* recombinant lactoferrin for each of the three lactoferrin variants, as depicted in FIGURE 1A, lane 1-4. Analysis of a duplicate gel by silver stain analysis showed that the lactoferrin variants were >95% pure and a single band at the expected molecular weight of ~80 kDa was observed for each of the proteins. See, FIGURE 1B, lane 1-4. Hence, the size and immunoreactivity of the lactoferrin variants were indistinguishable from *wild-type* recombinant lactoferrin.

**C. Example 2: The Iron Binding Defective Variants Of Lactoferrin Have Similar Enteric Receptor Binding Properties To Wild-Type Recombinant Human Lactoferrin**

Based on the similarity of the amino acids alanine and tyrosine, it could be assumed that single amino-acid substitutions of tyrosine to alanine residues in the iron binding lactoferrin variant would result in minimal structural to the protein. Thus, the activity of the iron binding defective variants which are independent of iron binding, should be similar to that of *wild-type* recombinant human lactoferrin. Applicants and others have previously shown the presence of specific and saturable receptors for iron-saturated lactoferrin on human enterocyte cells. Iyer *et al.*, 1993, *Eur. J. Clin. Nutr.* 47:232-241; Cox *et al.*, 1979,

*Biochem. Biophys. Acta.* 558:129-141; Hu *et al.*, 1988, *Biochem. J.* 249:435-441; Gislason *et al.*, 1995, *J. Pediatr. Gastroent. Nutr.* 21:37-43; Mikogami *et al.*, 1994, *Am. J. Physiol.* 267:G1-G8; Ward *et al.*, 1995, *Biotechnology* 13:498-503.

Hence, as a prerequisite to using competitive receptor binding assay for the iron  
5 binding lactoferrin variants, the relative receptor binding kinetics of iron-free  
versus iron-saturated recombinant lactoferrin needed to be established.

Competitive receptor binding assays were performed as described  
previously. Ward *et al.*, 1995, *Biotechnology* 13:498-503. Biotinylated iron-  
saturated recombinant human lactoferrin (0.4  $\mu$ M) was incubated with human  
10 enteric Caco-2 cell membranes in the presence of 0-20 fold molar excess of  
unlabelled apo- or iron-saturated recombinant human lactoferrin and a biotin/avidin  
microtiter assay was performed. Ward *et al.*, 1995, *Biotechnology* 13:498-503.  
The results of this analysis are shown in FIGURE 2A. Surprisingly, both apo- and  
iron-saturated lactoferrin showed comparable capacity to displace binding of iron-  
15 saturated biotinylated lactoferrin to the human enteric Caco-2 cell membranes  
indicating that both forms of lactoferrin have similar affinity for the lactoferrin  
enterocyte receptor. While lactoferrin has been proposed to deliver iron to  
enterocyte cells through these receptors, the similar relative receptor binding  
affinities of iron-free and iron-saturated lactoferrin suggest that the ability of  
20 lactoferrin to deliver iron via these receptors depends primarily on the relative  
amounts of iron-saturated versus iron-free lactoferrin present in the intestinal  
lumen.

Having established the affinity of apo-lactoferrin for its enteric receptor,  
competitive receptor binding assays with the lactoferrin variants were performed as  
25 described above to compare their functional activity with that of the *wild-type*  
protein. The results of this analysis are shown in FIGURES 2B, 2C, and 2D. All  
three iron binding defective variants showed no significant differences (< 2-fold  
variation) in their capacity to specifically inhibit the binding of iron-free  
biotinylated lactoferrin to Caco-2 membranes as compared to *wild-type* protein.  
30 These results indicate that mutation of the tyrosine residues did not disturb the  
iron-independent receptor binding functional activity of the protein.

**D. Example 3: Mutation Of The Tyrosine Residues Involved In Iron Binding In The Amino- And Carboxy-Terminal Lobes Of Lactoferrin Selectively Disrupts The Iron Binding Capacity Of The Mutated Lobes Of The Protein**

5 To confirm that mutation of the two tyrosine residues in either or both lobes of lactoferrin was sufficient to disrupt the iron binding ability of the mutated lobe, iron-saturation analysis using  $^{59}\text{FeCl}_3$  was performed.

The results of this analysis are shown in FIGURE 3. In the presence of a 4-fold excess of iron, the *wild-type* recombinant lactoferrin saturated at a 2:0 molar ratio of iron/protein as expected. While MN-2Y having an intact carboxy-terminal iron binding function was saturated at a 1:1 molar ratio, MC-2Y having an intact amino-terminus was saturated at less than 1:1 ratio indicating some possible iron loss from this lactoferrin variant at pH 7.0. Hence disruption of the tyrosine residues involved in iron binding in either the amino or carboxy terminal half o  
10 lactoferrin selectively abolished the iron binding ability of only the mutated lobe. In addition, the results from this analysis demonstrated that mutation of all four tyrosine residues involved in iron binding by lactoferrin effectively ablated the iron binding ability of this protein.

20 **E. Example 4: Cooperativity Between The Amino- And Carboxy-Terminal Lobes Of Lactoferrin Contribute To The Unique Iron Binding Stability Of This Protein**

Having established that the iron binding defective lactoferrin variants were similar to *wild-type* recombinant lactoferrin, as determined by size, immunoreactivity and receptor-binding analysis, the pH-dependent iron release  
25 from these lactoferrin variants was analyzed to determine the contribution of the two-lobe structure to the iron binding stability of lactoferrin.

The lactoferrin variants were saturated with  $^{59}\text{FeCl}_3$  and dialyzed against buffers ranging in pH from 7-2 for 48 hours at 4°C. The amount of iron  
30 remaining bound to the lactoferrin variants was quantified by liquid scintillation counting. The results of this analysis are shown in FIGURE 4. The iron release profile from MN-2Y, containing an intact carboxy-terminal iron binding lobe, was similar to that of recombinant lactoferrin, iron release beginning at a pH of 5.0 and completed at pH 2.0. In contrast, the pH dependent release of iron from MC-2Y,

containing an intact amino-terminal iron binding lobe, was markedly different. Release of iron from this variant began at a pH of 7.0, which is consistent with the lower than 1:1 iron saturation of MC-2Y (FIGURE 4). In addition, iron release from MC-2Y was completed at a pH of 5.0. These results indicate that the amino- and carboxy-terminal lobes of lactoferrin differ in their pH stability of iron binding and a functional iron binding carboxy-terminal lobe is required to confer an increased pH stability to the amino-terminal domain that is characteristic of the *wild-type* protein. Based on these observations, it can be concluded that cooperative interactions between the two halves of lactoferrin, driven primarily by the carboxy-terminal lobe, contribute to the pH stability of iron binding that is unique to this protein.

All references cited within the body of the instant specification are hereby incorporated by reference in their entirety.

## CLAIMS

## WHAT IS CLAIMED:

1. A nucleic acid sequence encoding a lactoferrin variant or portion thereof, wherein said portion is further defined to comprise a sequence corresponding to at least one iron binding site of lactoferrin, and wherein the lactoferrin variant or portion thereof has a modified iron binding capacity.
2. A nucleic acid sequence encoding a lactoferrin variant selected from the group consisting of MN-2Y, MC-2Y and MNC-4Y.
3. A recombinant vector comprising:
  - (a) a promoter;
  - (b) DNA encoding for the lactoferrin variant or portion thereof of Claim 1; and
  - (c) transcription and translation initiation and termination sequences;wherein said vector is capable of producing the lactoferrin variant and expressing same as a processed protein.
4. A vector adapted for the expression of a lactoferrin variant or portion thereof in a eukaryotic cell, wherein said vector comprises DNA encoding a lactoferrin variant protein or portion thereof of Claim 1 and regulatory elements necessary for the expression of said DNA in said cell.
5. A vector comprising:
  - (a) a nucleic acid encoding the lactoferrin variant or portion thereof of Claim 1; and
  - (b) a promoter, and transcription and translation initiation and termination sequences;wherein said vector is used for the expression of human lactoferrin in a eukaryotic cell.
6. A vector selected from the group consisting of p26MN-2Y, p26MC-2Y and p26MNC-4Y.
7. A transformed eukaryotic cell comprising the vector of Claim 5.
8. The eukaryotic cell of Claim 7, wherein said cell is selected from the group consisting of fungal, mammalian and insect cells.



9. The eukaryotic cell of Claim 8, wherein said eukaryotic cell is a fungal cell selected from the group consisting of *Aspergillus oryzae*, *Aspergillus niger*, *Aspergillus nidulans* and *Aspergillus awamori*.
10. A transformed eukaryotic cell comprising a vector of Claim 6.
11. The eukaryotic cell of Claim 10, wherein said cell is selected from the group consisting of fungal, mammalian and insect cells.
12. The eukaryotic cell of Claim 11, wherein said eukaryotic cell is a fungal cell selected from the group consisting of *Aspergillus oryzae*, *Aspergillus niger*, *Aspergillus nidulans* and *Aspergillus awamori*.
13. A method for producing the lactoferrin variant or portion thereof of Claim 1 which comprises the following steps:
- (a) transforming a eukaryotic cell with a vector containing:
    - i) the nucleic acid of Claim 1; and
    - ii) a promoter, and transcription and translation initiation and termination sequences;wherein said vector is adapted for the expression of the lactoferrin variant or portion thereof in a eukaryotic cell; and
  - (b) culturing said transformed eukaryotic cell in a suitable nutrient medium until lactoferrin variant protein is formed, secreted into the nutrient medium, and isolated therefrom.
14. A lactoferrin variant or portion thereof encoded by the nucleic acid of Claim 1.
15. A lactoferrin variant selected from the group consisting of MN-2Y, MC-2Y and MNC-4Y.

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FIG. 1A

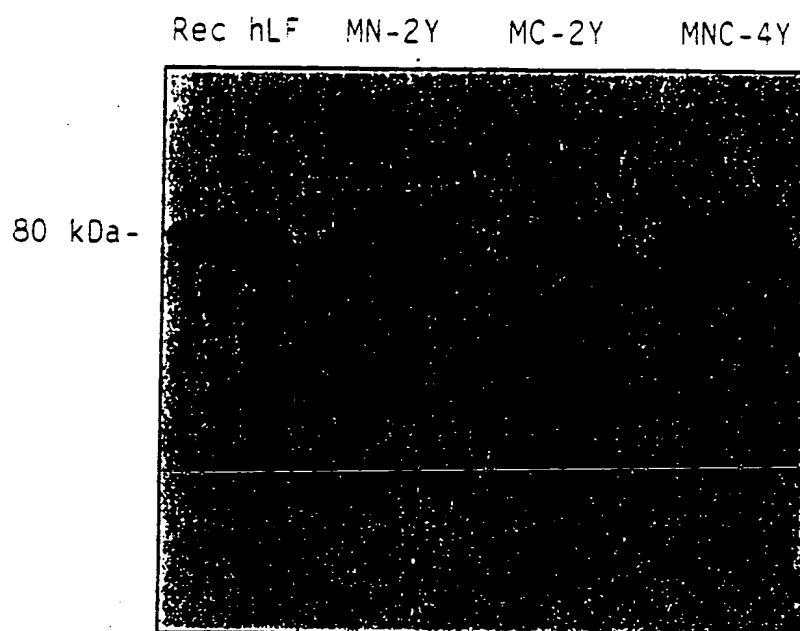
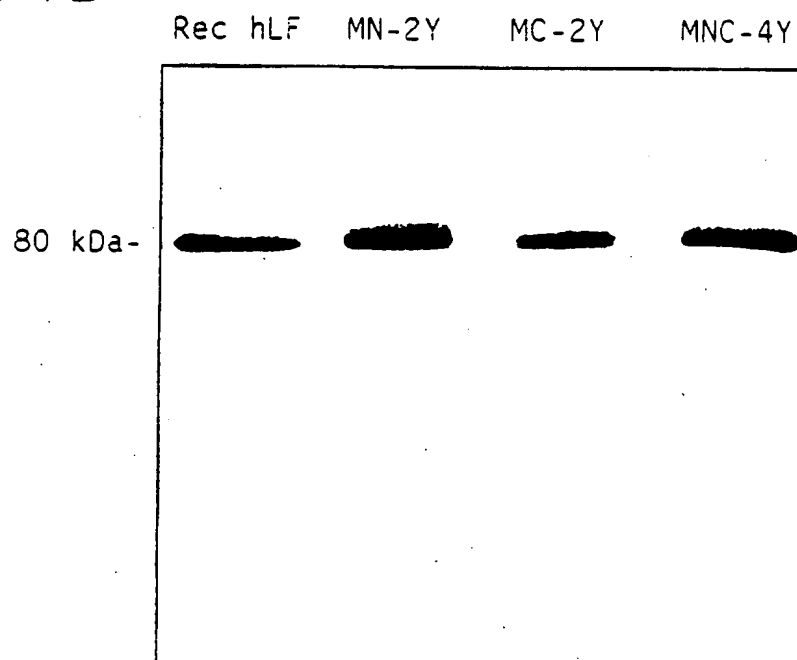
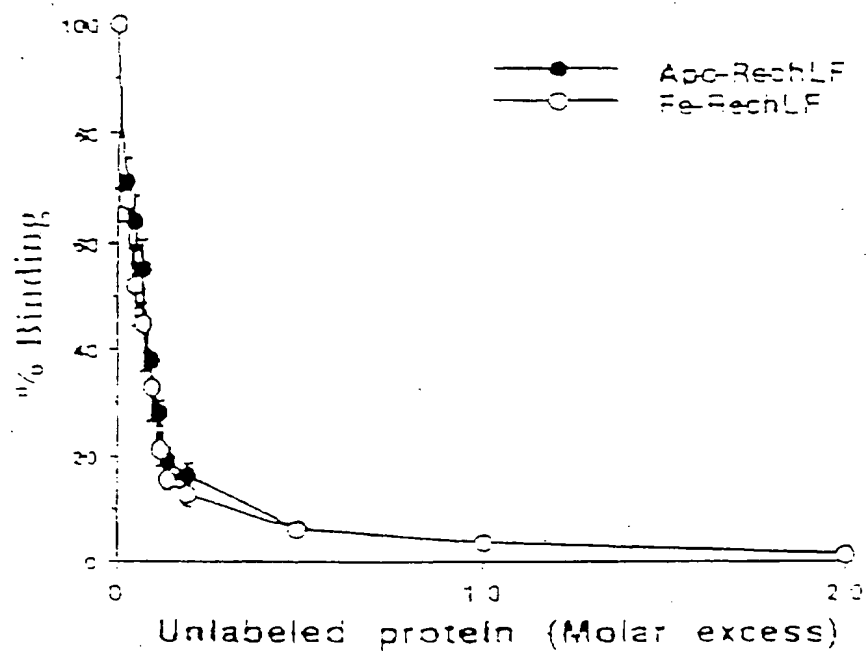


FIG. 1B



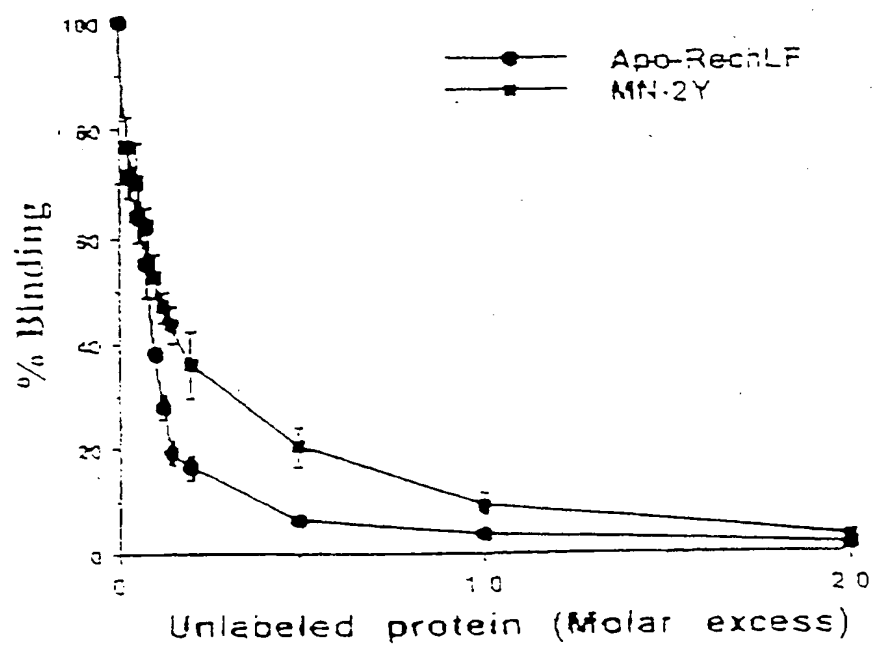
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FIGURE 2A



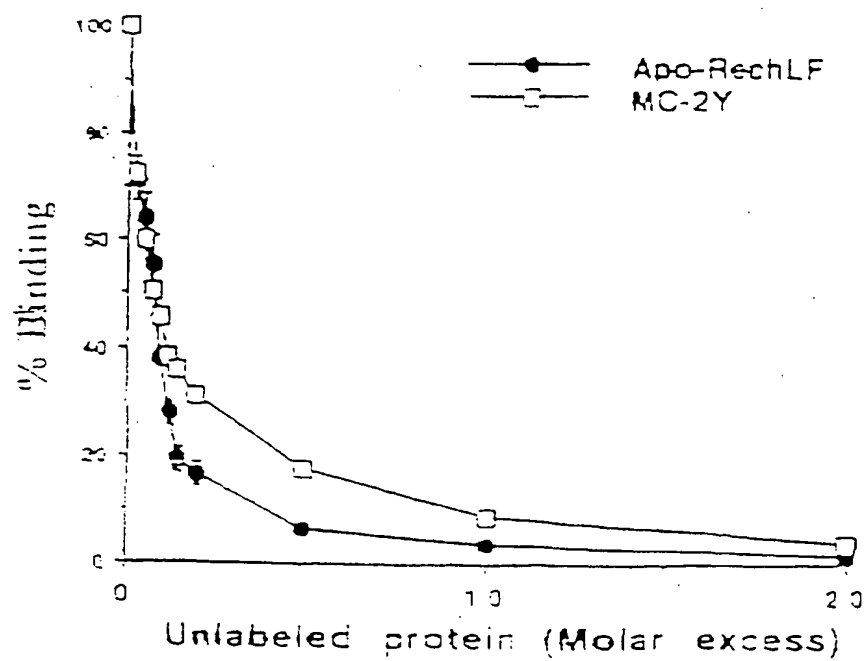
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FIGURE 2B



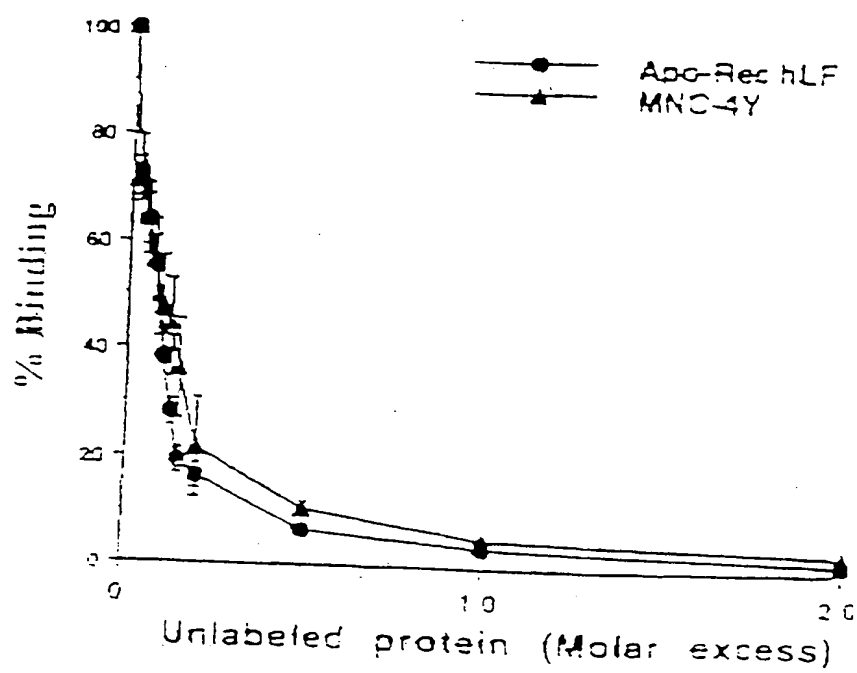
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FIGURE 2C



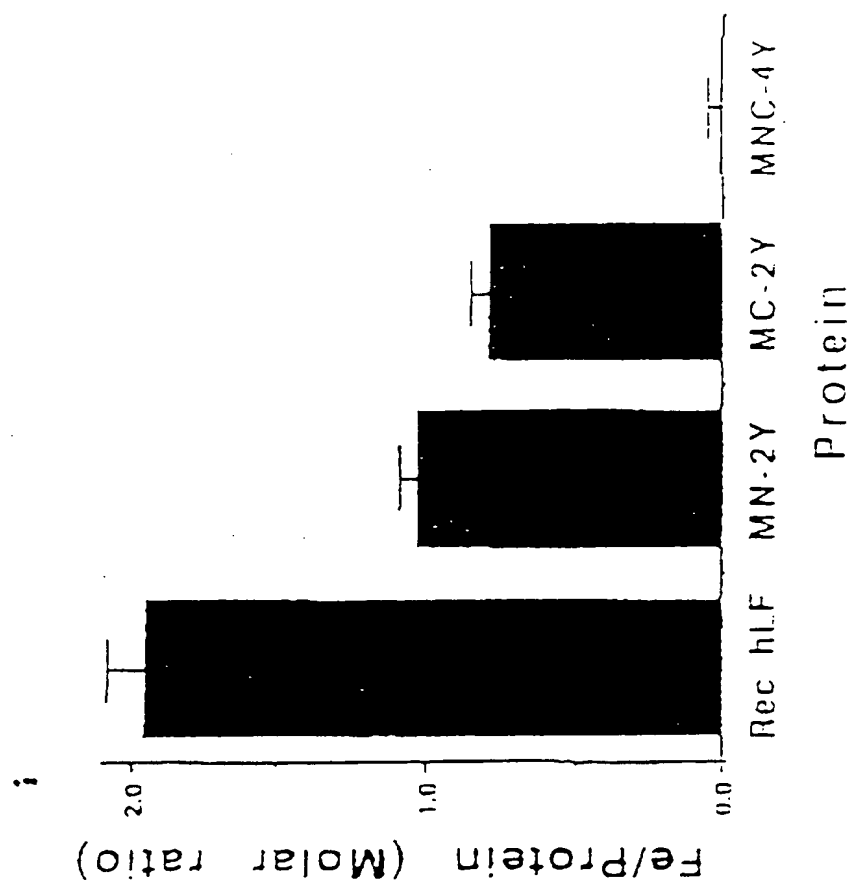
5/7

FIGURE 2D



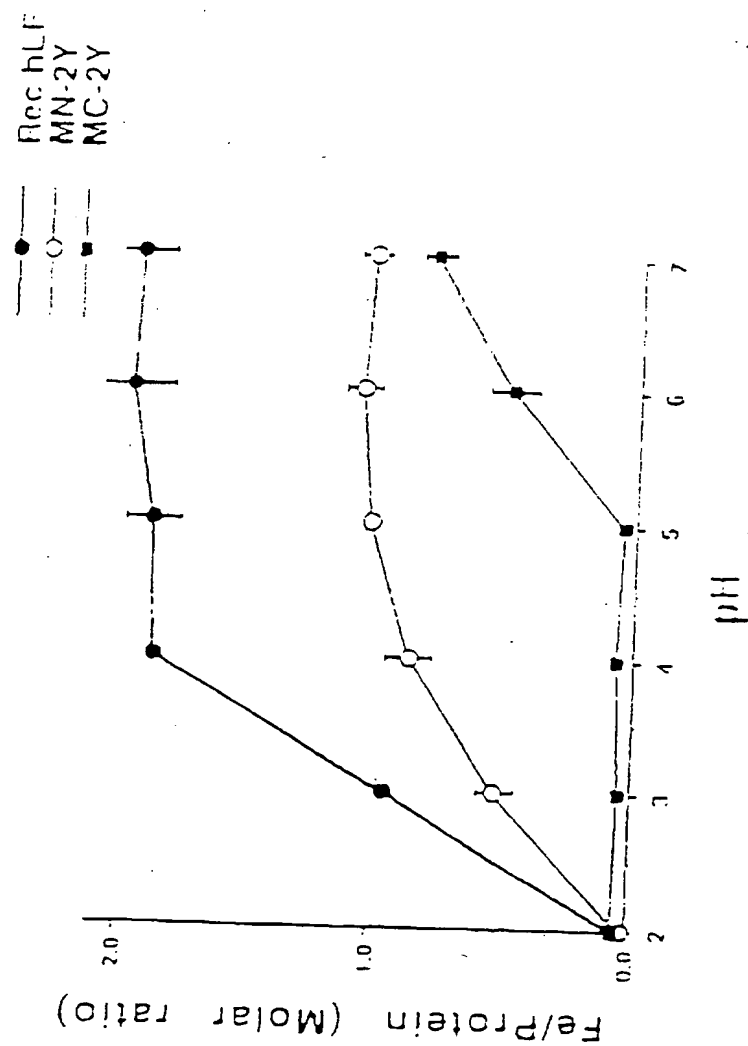
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FIGURE 3



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FIGURE 4





## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US97/09531**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(6) : A61K 38/40; C07K 14/79; C12N 15/12, 15/63, 15/79, 15/80, 15/85  
 US CL : 514/6; 530/400; 435/69.1, 69.7, 172.3, 252.3, 254.3, 320.1, 325  
 According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 514/6; 530/400; 435/69.1, 69.7, 172.3, 252.3, 254.3, 320.1, 325

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
 Please See Extra Sheet.

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	TWEEDIE, J. W. et al. Lactoferrin cDNA Expression and In Vitro Mutagenesis. Advances in Experimental Medicine Biology. 1994, Vol. 357, pages 197-208, especially pages 202-207.	1, 3-5, 7, 8, 13 and 14 ----- 9
X --- Y	DAY, C. L. et al. Studies of the N-terminal Half of Human Lactoferrin Produced from the Cloned cDNA Demonstrate That Interlobe Interactions Modulate Iron Release. The Journal of Biological Chemistry. 15 July 1992, Vol. 267, No. 20, pages 13857-13862, especially pages 13859-13862.	1, 3-5, 7, 8, 13 and 14 ----- 9

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	* T	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
* A* document defining the general state of the art which is not considered to be of particular relevance	* X*	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
* E* earlier document published on or after the international filing date	* Y*	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
* L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	* &*	document member of the same patent family
* O* document referring to an oral disclosure, use, exhibition or other means		
* P* document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search

14 AUGUST 1997

Date of mailing of the international search report

26 SEP 1997

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## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US97/09531

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WARD, P. P. et al. An inducible expression system for the production of human lactoferrin in <i>Aspergillus nidulans</i> . Gene. 01 December 1992, Vol. 122, pages 219-223, see entire article.	9
A	WO 91/13982 A1 (FERRODYNAMICS, INC.) 19 September 1991, pages 9-16.	1, 3-5, 7, 8, 13 and 14
A	DAY, C. L. et al. Structure of the Recombinant N-Terminal Lobe of Human Lactoferrin at 2.0 A Resolution. Journal of Molecular Biology. 05 August 1993, Vol. 232, pages 1084-1100.	14
A	SEYFERT, H.-M. et al. Lactoferrin: Interactions and Biological Functions. Totowa, NJ: Humana Press Inc., 1997, pages 61-79.	1, 3-5, 7, 8, 13 and 14
A	SHETH, B. et al. Cloning and Expression of the C-Terminal Lobe of Human Lactoferrin. Advances in Experimental Medicine and Biology. 1994, Vol. 357, pages 259-263.	1, 3-5, 7, 8, 13 and 14
A	LONNERDAL, B. et al. Lactoferrin: Molecular Structure and Biological Function. Annual Review of Nutrition. 1995, Vol. 15, pages 93-110.	14

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US97/09531

### B. FIELDS SEARCHED

Electronic data bases consulted (Name of data base and where practicable terms used):

DIALOG databases Medline, Current BioTech Abstracts, Derwent Biotechnology Abstracts, CA Search, Biosis Previews, Agricola, Derwent World Patent Index were searched. SEQ IDs NOs:4-7 and their inverse complements were searched in GenBank 99, GenBank-NEW 3, UEMBL 50-99, N-GeneSeq 26, GenBank-EST 99, GenBank-N-EST 3, and UEMBL-EST 50-99.

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